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WATER QUALITY BASELINE STUDY AND NON-POINT SOURCE POLLUTION ANALYSIS ON WAIKELE STREAM, WEST LOCH ESTUARY, OAHU, HAWAII

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By

Eduardo P. Manglallan

Thesis Committee:

Gordon L. Dugan, Chairperson
Yu Si Fok
Linda Hihara-Endo

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We certify that we have read this thesis, and that in our opinion, it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Civil Engineering.

THESIS COMMITTEE

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List of Acronyms

CFR- Code of Federal Regulations

CINCPACFLT- Commander in Chief U.S. Pacific Fleet

CZMA- Coastal Zone Management Act

DOD- Department of Defense

DOH- Department of Health

EPA- Environmental Protection Agency

ESQD- Explosive Safety Quantity Distance

FFCA- Federal Facilities Compliance Act

FWPCA- Federal Water Pollution Control Act

HAR- Hawaii Administrative Rules

NAVFAC- Naval Facilities Engineering Command

NAVMAG- Naval Magazine Lualualei

NRC- National Research Council

OSC- Oahu Sugar Company

PACDIV- Pacific Division Naval Facilities Engineering Command

PWC- Navy Public Works Center

RCRA- Resource Conservation and Recovery Act

SDWA- Safe Drinking Water Act

USGS- United States Geological Survey

WWTP- Wastewater Treatment Plant

Chapter 1

Introduction

1.1 Background

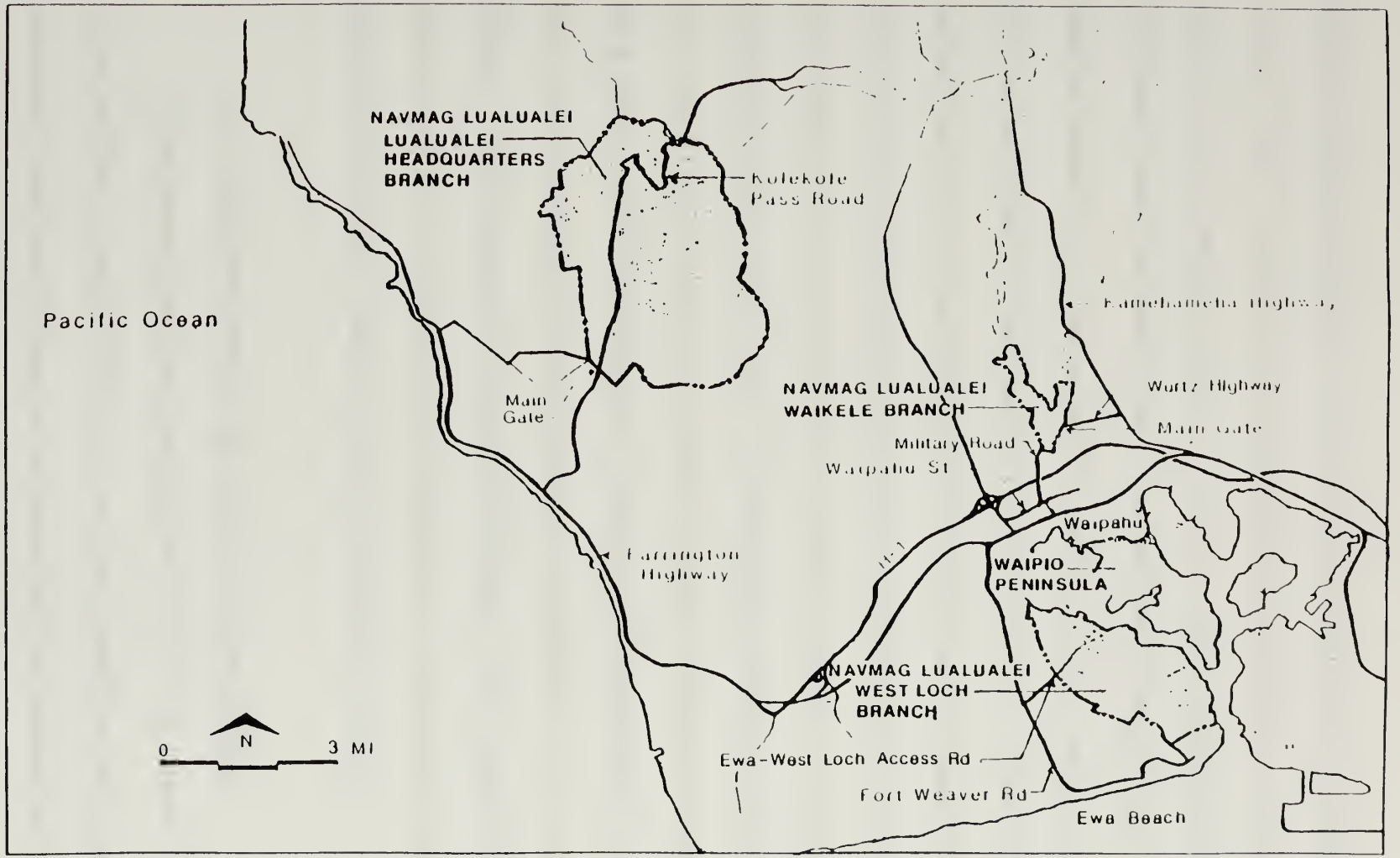
Americans care deeply about the environment, and they relate to the idea of living in harmony with it. More and more Americans call themselves environmentalists now than ever before as can be seen every day on television and other news media. In the fall of 1992, Money Magazine conducted a survey of the qualities Americans look for in a place to live. Clean water ranked the highest, and the quality of the environment ranked sixth. America's leaders have translated that interest into a political support and have made record progress in improving their environment at taxpayer's expense. Americans like to live in a clean and safe environment, but more often than not, they demand more than they can offer and afford. With the advent of stringent federal and local environmental laws, the United States is leading the world in trying to correct and undo its past mistakes. The former EPA Administrator, Mr. Bill Ruckelshaus once remarked, "all of our rivers and streams may not be fishable and swimmable yet, but at least they are no longer flammable" (Wilcher, 1993). Much had been done in mitigating point source water pollution, and greater attention is now directed towards non-point source water pollution.

1.2 Waikele Stream and West Loch Estuary Physical Setting

Waikele Stream is located on the central plains of the island of Oahu, with a drainage area of about 45.7 square miles and a flow range of 3.7 cfs to 13,600 cfs (Jones et al., 1971). A U.S. Geological Survey (USGS) stream-quality gaging station is in place along Waikele Stream. The gaging station is located on the left bank of the stream 300 feet upstream from bridge on Highway 90 and 0.3 mile southwest of the sugar mill at Waipahu (Matsuoka et al., 1992). The island of Oahu is the third largest of the Hawaiian Islands with about 608 square miles of land area. It houses almost 80 percent of the State's people and is the center of government and industry (Armstrong, 1983). Military bases and training areas occupy about 26 percent of Oahu's land. Large areas of land are used by the military for live-firing, training, and for the storage of ammunition. Most of the 520 acres of land at Waikele Branch consists of steep slopes and cliffs faces covered by Leucaena leucocephala (koa haole) shrub. Ground cover consists almost exclusively of dense Panicum sp (Panic) grass with localized patches of Tricholaena rosea (Natal redtop), Digitaria insularis (Sour grass), and Panicum maximum (Guinea grass). The relatively level gulch floors and gently sloped areas are covered by a closed to open Leucaena (koa haole) forest and other tree species. Dense Guinea grass covers the ground layer beneath the forest. Streamside vegetation along the banks of the Kipapa and Waikele

Streams is characterized by thick Guinea grass and various Pennisetum purpureum (Napiergrass), weedy species such as Ricunus communis (castor-oil bean), Pluchea, and bitter gourd. The natural contour and hard clay soil along the streams made the construction of the tunnel magazines as well as some earth covered magazines feasible which had been in operation since the 1930's. A small arms range was constructed on Waikele in 1955 which was located at the north end of Kipapa Stream Gulch. This range was demolished because the surface danger zone extended off-station. The upstream end on the Army side of Waikakalaua Stream is currently outleased to a private agricultural and cattle grazing firm. During the Navy wildlife survey in 1985, there were no plant or animal species listed on the U.S. Federal list of endangered and threatened species, or proposed, rare, or depleted species (NAVFAC, 1989).

The West Loch Branch of NAVMAG Lualualei as shown in Figure 1 include Waipio Peninsula, and incorporates most of the West Loch Estuary. This branch contains approximately 5,000 acres of land that provides the Navy's port facilities for loading and off-loading ammunition and explosives, operations and maintenance buildings, and magazine facilities. A major portion of West Loch including all of the station's property at Waipio Peninsula lies within the Pearl Harbor Historic Site. The Okiokilepe Fish Pond located at West Loch is currently listed on the



Source NAVMAG Lualualei Master Plan

Figure 1. NAVMAG Lualualei Location Map

National Register of Historic Places. The pond has been identified as being of historic importance because it is the only fish pond left in Pearl Harbor where many had existed in the past. The 4.5-acre pond is significant since it is constructed of stacked coral blocks rather than basaltic stone which was commonly used in the construction of other fish ponds in the Hawaiian Islands (NAVFAC, 1989). A flora and fauna survey conducted by the Navy in 1985 at West Loch revealed that 121 species of plants were recorded. No plant species currently listed on the U.S. Federal list of endangered and threatened species or proposed, rare, or depleted species were found. The Honouliuli Wildlife Refuge at West Loch has a total of twenty-one species of birds. Two species observed were native. One of the native bird species is the short-eared owl, or pueo, is on the State of Hawaii's listing of endangered and threatened species. Furthermore, its listing is limited only to the island of Oahu. However, no U.S. Federally listed endangered or threatened avifauna species were known to exist at West Loch (NAVFAC, 1989).

1.2.1 Explosive Safety Quantity Distance (ESQD)

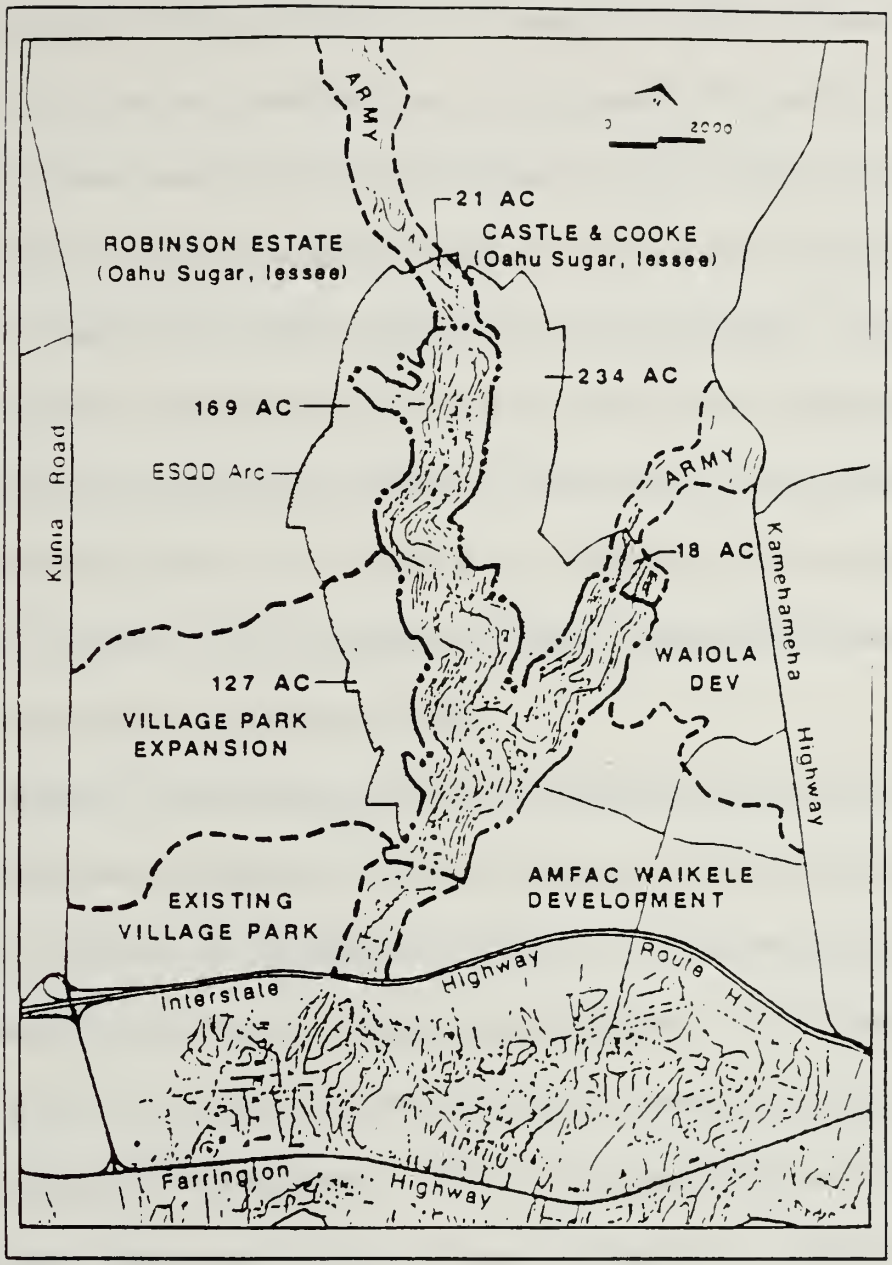
Hazard zones have been established by the Department of Defense Explosive Safety Board (DDESB) for various quantities and types of explosives. Minimum distances are prescribed for separating explosives from inhabited structures, from public roads, and from other explosives.

These distances are called Explosive Safety Quantity Distance (ESQD). It is based on the cube root of the quantity of explosives stored, multiplied by some factor based on the type of explosive stored (NAVSEA, 1992). The ongoing residential, industrial, and recreational developments around the perimeter of NAVMAG Waikele Branch as shown in Figure 2, had an operational impact on the quantity of ammunition that can be stored in the magazines in order to maintain the ESQD arc. Because of this urban development encroachment, along with austere DOD budget, the Navy closed down the NAVMAG Waikele Branch in 1993 and made it available for other DOD users with no ESQD requirement.

The associated ESQD arc at West Loch encumber a majority of the West Loch Estuary and Waipio Peninsula. The ESQD hazard zone emanating from the Whiskey wharves at West Loch constitute the major development constraint. This constraint makes West Loch to be relatively unused as compared to the other Lochs near Pearl Harbor. The encumbered vacant land on the outer sixty percent of the arc is outleased for sugar farming (NAVFAC, 1989).

1.2.2 Geology and Terrain

The geology of the Hawaiian Islands is remnants of eroded peaks of a submerged mountain range extending approximately 1,600 miles across the Pacific Ocean from the northwest to the southeast. The island



Source: NAVFAC, 1989.

Figure 2. Waikele Encroachment

of Oahu, third largest in the Hawaiian Island chain, covers an area of approximately 608 square miles. It consists of eroded remnants of two shield volcanoes and some sedimentary deposits. The western mountain range of Oahu was formed first by lavas from the Waianae volcano, while the eastern mountain range was formed as lava from the Koolau volcano piled up against the eroded slopes of the Waianae Dome. The relatively coastal plains to the north and south are composed of sedimentary deposits that were formed after most of the volcanic activity from the two volcanoes had ceased. Elevations on the island vary from sea level to about 4,025 feet at the top of Mount Kaala, located in the Waianae Mountain Range (Armstrong, 1983).

Waikele Stream originates in the Waianae Range at an elevation of 2,575 feet above mean sea level, flowing eastward for about eight miles where it is joined by Waikakalaua Stream. The Waikakalaua Stream originates from the Koolau Range at an elevation of 2,681 feet above mean sea level and flows westward for about sixteen miles before joining Waikele Stream (Murabayashi, 1983). The Kipapa Stream which starts at Mililani merges with Waikele Stream forming a "Y" pattern at the NAVMAG Waikele Branch. Waikele Stream flowrate, between 3.7 cfs and 13,600 cfs, as reported by Jones et, al. (1971), is the same as reported by Nakahara, et al. (1972); Ekern (1977); Doty, et al. (1981); Eyre (1983); Murabayashi, et al. (1983); and Matsuoka, et al. (1992).

The major soil types along Waikele Stream are Haleiwa silty clay, and rock land. The Haleiwa silty clay is a well-drained, dark-brown soil on nearly level alluvial fans and drainage ways. Few gravel and sand deposits occur in the subsoil, and the depth to the bedrock is more than five feet with a moderate permeability. The rock land consists of areas that have 25 to 90 percent exposed rock (Eyre, 1983). Among the rocks are soils that are only a few inches deep. The stream beds are relatively flat, while the slopes of the bluff areas along the stream vary from 30 percent to about 70 percent. The area below the USGS gaging station located about 0.5 mile from the mouth of Waikele Stream entering West Loch is called Waikele Spring. The average spring flow from 1973 to 1978 was about 12.7 mgd (Murabayashi et al., 1983). Three rain gage stations located near the vicinity of West Loch have an average annual median of about 23-inch (Taliaferro, W.J.; 1959), and annual evaporation mean of about 53-inch (DLNR, 1973).

1.3 Purpose and Scope

The purpose of this thesis is to establish a water quality baseline on Waikele Stream, and West Loch Estuary now that the Mililani WWTP no longer discharges effluent into Waikele Stream. Grab samples will be collected weekly from each of the six pre-selected sampling stations along Waikele Stream up to and including West Loch Estuary following the

procedures per Standard Methods (1992), 18th edition, Sections 1060A and 1060B. The collected water samples will be tested at the Navy Public Works Center (PWC) Environmental Laboratory. The duration of sampling and the number of pollutant analysis will depend on the availability of funds to support the required laboratory tests per the current PWC rates as listed in PWC Pearl Notice 7030 (1993). The obtained results will be analyzed and compared with available water quality data on Waikele Stream before August 1986 when the Mililani WWTP terminated discharge of effluent into Waikele Stream. The results will be also compared with the State of Hawaii DOH (1990) Water Quality Standards.

Chapter 2

Literature Review

2. 1 Water Pollution History

Point source water pollution is largely a function of available waste disposal technology. In the nineteenth century, industries disposed untreated waste directly in water bodies, subject only to minimal restrictions, and the technology for disposing human wastes was even more primitive. Industrial waste disposal practices continued virtually unrestrained until after World War II because water pollution from industrial waste was not seen as a major threat then. Initial efforts were concentrated on human waste. The use of cesspool, privy vault, and scavenger systems were replaced by sanitary sewers. The spread of water polluted with fecal matter created serious health hazards and grave concern.

Public health officials viewed overflowing cesspools with water closet connections as a dangerous threat to a healthful environment. There were arguments over adoption of the water-carriage system that focused on economic considerations, health factors, and questions of comparative urban advantage. Water-carriage, and water supply systems, represented the most expensive capital projects undertaken by local municipalities in the nineteenth century (Miller, 1974). The

advocates of the water-carriage system argued that the benefits were greater than the costs as compared to the annual charges for collection under the cesspool, privy vault, and scavenger systems. With the expectations of health benefits, the water-carriage technology was implemented, but it was found to produce repercussions farther downstream and onto neighboring cities.

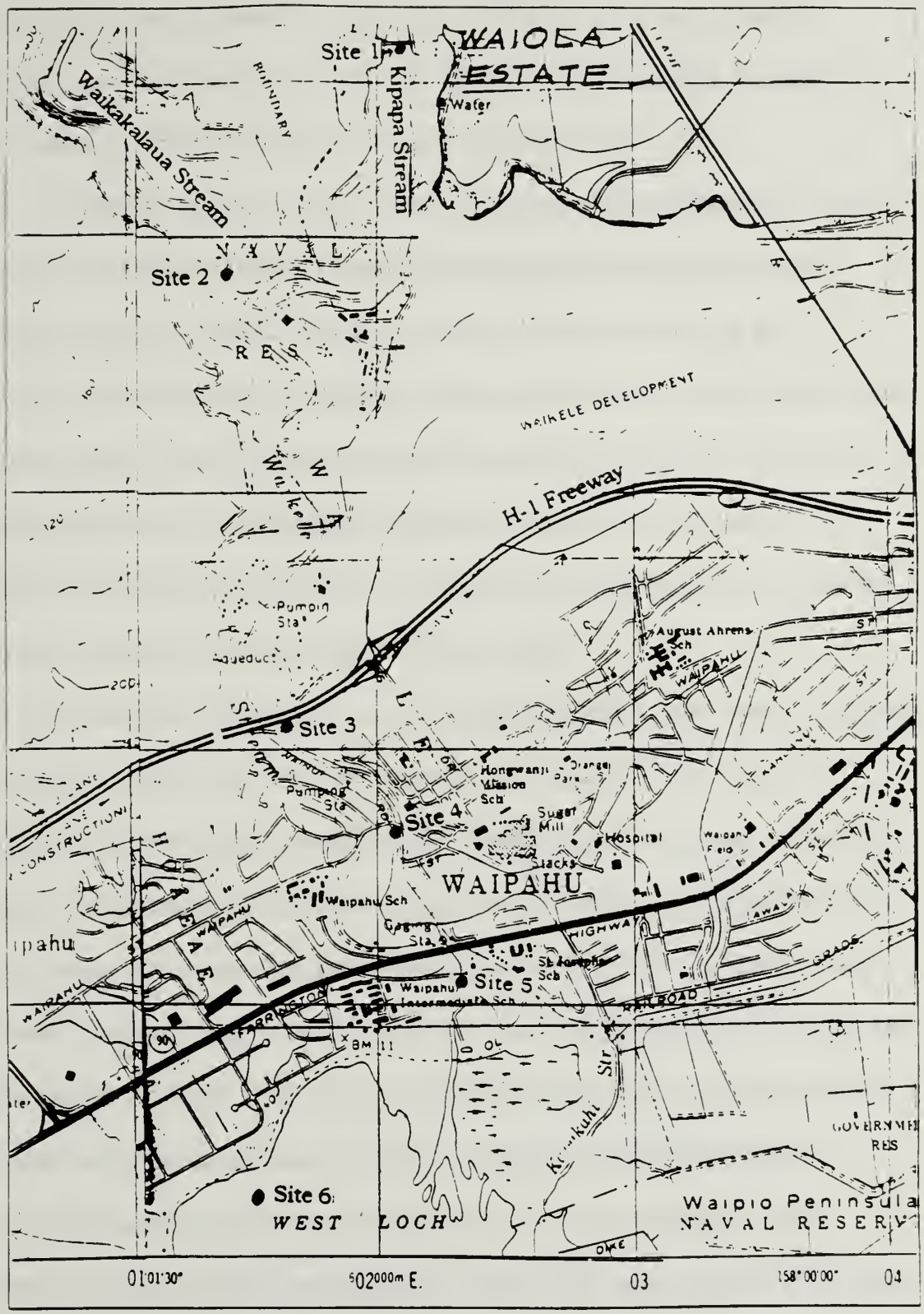
The adverse health effects of sewage polluted streams and waterways were high mortality rates, restricted water use for manufacturing purposes, and recreational purposes (Nemerow, 1974). The logical source of relief for municipalities and individuals suffering from the effects of the polluted water was the courts. Engineers and city officials traditionally viewed waterways as the natural vehicles for wastes under the old assumption that running water purified itself and that the dilution would eliminate hazard (Grace, 1978).

After World War II, water pollution control was legislated to be a local and state responsibility. The Federal Water Pollution Control Act, now referred to as the Clean Water Act (PL 92-500) was a federal effort to eliminate all pollution by imposing technology-forcing standards on effluents discharged, as opposed to setting standards for the quality of receiving waters. The technology-forcing, effluent limitations policy to eliminate pollution was put in place in 1972 and remains the basis of the program. The CWA provided for the creation of a National Commission

on Water Quality to assess the impact of the Act and to recommend corrections. The 1976 Water Quality Commission report to Congress recommended the inconsistent approach of keeping the 1983 interim goal, but redefined the 1985 no-discharge goal to stress conservation and reuse, and extended deadlines (Anderson, 1990). CWA divided water pollution as either point source or non-point source. Point source was broken down into municipal sewage treatment plants, and industrial discharges. Both types of point source need to apply for a permit issued by the federal government or a qualified state agency. The National Pollution Discharge Elimination System (NPDES) permit established the effluent limitations and a deadline for meeting them. EPA generally issues full five-year permits subject to modification or revocation for cause (West, 1993).

2.1.1 Waikele Stream/West Loch Estuary Pollution

The Kipapa Stream from Mililani Town and the Waikakalaua Stream from Leilehua Plateau, merge at the Waikele Branch of NAVMAG Lualualei forming Waikele Stream. It then traverses the town of Waipahu, and finally into West Loch Estuary as shown in Figure 3. The West Loch Estuary and Waikele Stream receive non-point source surface water run-offs from adjacent agricultural land, and existing and new urban development. The amount of non-point source pollution on West



Source: Defense Mapping Agency

Figure 3. Location of Sampling Stations

Loch and Waikele Stream is unknown. There is no known existing treatment on this surface water run-off before entering the navigable waterways on West Loch other than natural process.

According to the City and County of Honolulu Wastewater Branch records, the Mililani WWTP ceased discharging effluent into Waikele Stream in August 1986. This was made possible as soon as the Honouliuli WWTP sewer interceptor came on the line. Prior to World War II, water uses in Pearl Harbor included yachting, fishing, swimming, and shellfish collecting. Progressive pollution since then has caused the harbor to be placed "off limits" to all such activities because of reported pollution and security reasons (FWPCA, 1969).

The sources of pollution in the 1969 FWPCA report were: untreated or partially treated wastes from federal, municipal, and industrial sources (i.e., city dumps, outfalls), and agricultural sources. It was also noted in the report that heavy loads of settleable and suspended solids (4,250 tons/yr) was being discharged into West Loch, and had reduced the size of certain major oyster beds by more than 50 percent during the period 1963 to 1969. The State of Hawaii Department of Health (1990) adopted a new coastal water quality standards in which all of Pearl Harbor, including West Loch, was placed in a new category, "Pearl Harbor Estuary," which more closely reflects the conditions in the harbor than the previous classifications of "A" and "AA" (FWPCA, 1969).

2.2 Population Growth and Economic Development

Although significant progress has been made in improving the nation's water quality over the last twenty years, many coastal areas continue to suffer from persistent environmental problem and can expect to encounter new problems in the future. At least 37 percent of the U.S. population live in counties adjacent to the oceans or to major estuaries, most of them in concentrated urban areas (Hardin, 1993). The waste from this population and its associated activities is a major source of widely documented deterioration of ocean and coastal waters. As the U.S. population grows, most coastal water-quality problems result from human activities associated with populations concentrated along the coasts and from land-use practices throughout the coastal watersheds (Cheremisinoff, 1993).

With population growing, economic development must also grow in order to equalize the supply and demand of economic goods, and to maintain a sustainable development. Economic development is defined as "the development path that maximizes the long-term net benefits to humankind" (Gillis et al., 1992). Development is an important concept for all societies, but as development expands, a potential threat in the degradation of resources and environment is imminent if not properly planned. Effective and proper planning will minimize resource-depletion

rate, maximize the benefits from resource use, and maintain economic growth (Helweg, 1985).

The State of Hawaii in particular is facing a considerable economic pressure in the sugarcane and pineapple industries. Apart from military operations and tourism, the economic mainstay of the islands is agriculture. With 26 sugar mills in 1972, Hawaii produced about 1.2 million tons of sugar, compared with about 1.5 million tons for the mainland's cane producers. The 240,000 thousand acres of land cultivated for cane brought about $1.6 billion to the islands each year (Miller, 1974). Numerous sugar mills have closed down since 1973, because of EPA cracking down on the industry to abandon waste disposal practices which have been standard for many years. Lately, Hamakua Sugar, one of the largest sugar company on the island of Hawaii was on the "spotlight." Due to low return on investment caused by high wage rates as compared with mainland and foreign counterparts, and environmental violations with expensive pollution control measures is forcing the company to shut down. On the island of Oahu, urban sprawl along with tough foreign competition and strict environmental compliance have caused one pineapple company to cease operation, and may force the last remaining sugar company to shut down.

2.2.1 Economic Benefit-Cost Analysis

Every decision to promote environmental quality at the expense of some other objective has an opportunity cost. Benefit-cost analysis is a tool used by the Army Corps of Engineers and Department of Interior to judge the comparative merits of an alternative flood control and reclamation project investments (Helweg, 1985). The benefit-cost analysis produces a ratio of benefits to costs for a proposed project. A project is considered justified if the benefit-cost ratio is in excess of "unity" (Collier et al., 1982). Decisionmakers also use benefit-cost analysis to make choices among alternative projects by usually selecting the project having the highest benefit-cost ratio (Thuesen et al., 1984). Benefit-cost analysis in the environmental arena is closely analogous to the methods of investment project appraisal used by businessmen. The only difference is that estimates of social value are used in place of estimates of sales value. This makes it difficult to appraise a fair benefit-cost ratio, as each society has differing social values and culture.

2.3 Potential Sources of Stream Water Pollutants

Pollutants enter estuarine and marine waters via several pathways, such as: piped outfalls, discharges and dumping from ships, riverborne discharges, sewage-sludge dumping, atmospheric deposition, and non-point source runoff from land. Estuarine and marine environments

have been used as major repositories of anthropogenic wastes for decades (Kennish, 1992). Shallow estuarine and coastal marine ecosystems were gradually subjected to significant impacts not only in sensitive habitat areas, but also in aquatic communities inhabiting them. More than 1,400 municipal wastewater treatment plants provide service to these coastal populations and discharge approximately 10 billion gallons of treated effluent per day. Approximately 85 percent of this effluent is discharged into bays and estuaries rather than open ocean (EPA, 1992). More than one hundred municipalities serving approximately 16 million persons have combined sanitary and stormwater sewers that overflow at approximately 1,800 points along the coast (NRC,1993). In addition to municipal discharges, approximately 1,300 industrial facilities are permitted to discharge about 11.3 billion gallons per day of treated industrial wastewater and spent cooling water to marine waters (EPA, 1992). The intensive use and misuse of the land, water, and air resources due to population expansion and the increasing level of pollution that comes with an increasing standard of living have augmented the widespread pollution of streams, lakes, and coastal urban areas (Tan, 1994).

In Hawaii, machineries that are being used in cane harvest gathers, in addition to the cane, huge amounts of mud and rocks which must be removed at the plant by water and mud baths. Open burning is

traditionally used to burn the cane leaves in the fields before harvesting. Once the cane is harvested and brought to the mill, water consumption in the cleaning process according to the EPA, wastewater flow rate run about 10 million GPD for a plant that produces about 200 tons of raw sugar per day (Miller,1974). The EPA reports that the facilities for mitigating sugar mill wastes are available. But the problem is more of economics than technology (Opschoor et al., 1991). Oahu Sugar Company for example, use a major portion of the leased Navy land on Waipio Peninsula near the shore line of West Loch which is encumbered by the ESQD arc as sedimentation ponds.

Potential leachate from sanitary landfills near-shore could result in infiltration due to relatively porous coral material at Waipio Peninsula (PWC, 1973). A leachate evaluation and monitoring project from August 1981 until October 1990 at Kapaa Sanitary Landfill next to Kawainui Marsh in windward Oahu, revealed a high annual median COD concentration of 325 mg/L. However, an outstanding characteristic of a typical leachate from landfill operations is a high COD concentration, or organic content, of about 18,000 mg/L (Dugan, 1991).

2.3.1 Solids

Turbid waters usually contain coarse sediment or fine suspended and dissolved solids. Solid impurities in traces are universal for water.

Even the freshly falling rain water is never near distilled. The presence of solids in water can be determined by a turbidity test, secchi disc, conductivity, hardness test, and sedimentation. Potable water usually contain total solids (essentially total dissolved solids) from 20 to 1,000 mg/L, and as a rule, hardness is directly affected by total solids (Sawyer et al., 1978). Analytically, total solids include both the total suspended solids (TSS) and total dissolved solids (TDS). Water with a high solid content is inferior and may be polluted (Ambasht, et al., 1990). Suspended solids in quiescent stretches of a stream will impair the normal aquatic life of a stream. TSS can be removed from the water by screening, filtration or by sedimentation (Eckenfelder, 1989). Waters with high dissolved solids are unpallatable and aesthetically unsatisfactory for drinking, bathing, and washing. TDS concentrations greater than 1,000 mg/L indicates corrosive conditions (Helweg, 1985). Combination of settling, coagulation and filtration process has been usually used in the removal of dissolved solids (Cheremisinoff, 1993). Suspended solids are often associated with biochemical oxygen demand, while dissolved solids are often associated with chemical oxygen demand (Powell, 1976).

2.3.2 Nutrients

Nutrient loads of nitrogen and phosphorus can deplete the

dissolved oxygen in the water by direct oxygen uptake in the case of oxidation of ammonia to nitrites and on to nitrates or by providing nutrients which can lead to aquatic biomass production. This has been shown to be true by numerous monitoring studies of dissolved and biochemical oxygen demand levels in the lower Hudson River in New York (Ott, 1978). Sources of nitrogen related to human activity include treated and untreated domestic sewage and industrial wastes, leachates, atmospheric deposition, and surface runoff (DePinto et al., 1994). Land-based and aquatic plants require vitamins and nutrients to grow. Required elements for most green plants are carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, sulfur, and other trace elements including magnesium and zinc (Tan, 1994).

All organisms must have nitrogen to live. Lightning causes the nitrogen and oxygen in the air to form nitrogen oxide compounds. These oxides react with water to form nitric acid, which is carried to the earth and dissolved in rainwater. The plants use these nitrogen oxide compounds to make protein. After the plants die and decay, the nitrogen compounds become part of the soil. As nitrogen is used and reused by living things, it goes through a continuous cycle of chemical changes which is known as nitrogen cycle. Some nitrogen compounds contribute to the pollution of both water and air (Sawyer et al., 1978).

Depending on the pH of the solution, nitrogen can exists in

aqueous solution as either the ammonium ion (NH_4^+) or as ammonia (NH_3). Further bacterial action oxidizes the ammonia nitrogen to nitrite nitrogen (NO_2-N) and then to nitrate nitrogen (NO_3-N). This process is called nitrification (Eckenfelder, 1989). A reverse process called denitrification returns an approximately equal amount of nitrogen back to the air. Nitrites are hardly found in nature because they are unstable and can be readily oxidized to nitrate form. The nitrate formed can be used as fertilizer for plants. Excess nitrates that are not used by plant life are carried away in water by percolation. This results in high concentrations of nitrates in groundwater. It was found mostly in the midwestern states that drinking waters with high nitrate content often caused methemoglobinemia in infants (blue babies). EPA requires that the nitrate concentration in terms of nitrogen not exceed 10mg/L in public water supplies (EPA, 1993a).

Nitrates and phosphates can have their origin in human wastes. More prolific sources of phosphates, however, are detergents. It has been estimated that 60 percent of the phosphorus in domestic wastewater has a detergent origin. High input of nutrients, such as nitrogen and phosphorus can lead to rapid and excessive algal growth. Algal decomposition can consume the oxygen content of the water body, and in the extreme lead to anaerobic conditions and accelerated aging of an aquatic environment known as eutrophication (Kennish, 1992).

2.3.3 Heavy Metals

Metals are substances that have large electrical and heat conductivity, metallic luster, malleable, and are ductile. Eighty of the elements in the periodic system are considered metals. They can be distinguished into alkali metals (Li, Na, K, Rb, and Cs), alkali-earth metals (Be, Mg, Ca, Sr, Ba, and Ra), and transition metals (Al, Fe, Mn, Cu, and Co). Some heavy metals are natural components of water, but some industries are noted for releasing certain elements. Electroplating can release chromium, cadmium, copper, nickel, silver, and zinc (Tan, 1994). Some of these metals (e.g., copper and zinc), although essential for proper metabolism of biota at lower concentrations, are potentially toxic to estuarine organisms above a threshold availability. Moreover, metals such as cadmium, lead, and mercury, which serve no biological function, can be hazardous even when small quantities are added via anthropogenic activity.

Trace elements leading to severe contamination problem in some coastal habitats include arsenic, cadmium, chromium, copper, lead, mercury, selenium, and silver. These are commonly of greatest concern in estuaries and coastal marine rivers. The highest concentrations of heavy metals are reported in biota inhabiting locally polluted habitats rather than in higher trophic level organisms attributable to a biomagnification effect. Heavy metals may also form organometal

complexes that can be particularly hazardous to estuarine and marine communities (Moore, 1991). Lead and mercury are abundant in volcanic and igneous rocks. If these rocks are constantly weathered and leached by rainwater, the metals are carried by runoffs into rivers, streams, and coastal waters (Okamoto, 1993). This type of pollution has affected the closure of about 37 percent of the estuarine waters that were classified as commercial shellfish beds (NOAA, 1991).

2.3.4 Chlorinated Hydrocarbons

Estuaries are accumulation sites of stable chlorinated compounds used by man as biocides (insecticides, herbicides, and fungicides) and as substances for a variety of industrial applications. These chlorinated hydrocarbon compounds resist breakdown in aquatic habitats and may persist for many years in the estuarine environment. In addition to DDT, an extensive list of chlorinated compounds was developed for use as commercial pesticides, including but not limited to aldrin, chlordane, endrin, heptachlor, dieldrin, perthane, and toxaphene (Ware, 1983).

DDT was put into global use in 1945 to ameliorate the spread of diseases transmitted by insects and to mitigate insect-related problems in aquaculture and forestry (Reutergardh, 1980). Chlorinated benzenes and phenols, as well as polychlorinated biphenyl (PCB) are a group of synthetic halogenated aromatic hydrocarbons that have been linked to a number of environmental and public concerns. PCB was first produced

in 1929, and rapidly gained widespread use because of their unique physical-chemical properties, including chemicals and thermal stability, miscibility with organic compounds, high dielectric constants, nonflammability, and low cost. It has been scrutinized extensively in the 1970s when their presence in aquatic environment was initially perceived as a serious contamination problem. Commercial production of PCB ceased in 1977, but an estimated half billion kilograms (~1.2 billion lbs.) had been produced in the U.S. for the manufacture of adhesives, caulking compounds, hydraulic oil additives, capacitor fluid, fluorescent light ballasts, paints, varnishes, fire retardants, plastics, carbonless copying paper, newsprint, and other materials (Whelan, 1985). The electric utility industry desired the insulating capacity and nonflammable characterisitcs of PCBs that are used as insulating fluids in electrical transformers and capacitors. Where they were once elevated, concentrations of PCB, DDT, and lead in coastal fish, shellfish, and sediments are decreasing (NOAA, 1990).

2.3.5 Oil Pollution

The probability of major oil spills is low, but their immediate impacts on coastal ecosystems and local industries (i.e., fishing, tourism) can be devastating. Of greater consequence, however, are the thousands of unpublicized small spills and leaks (i.e., illegal disposal of used

automobile crankcase oil in storm drains) that occur daily in urban coastal areas may add up to large chronic inputs of petroleum hydrocarbons (Ellis, 1989).

Estimates based on state-of-the-art cleanup technology indicate that as much as 80 percent of the oil accidentally discharged into the environment remains and is not removed. Spills occuring in oceans or bays are usually blamed on ships, especially tankers, since these incidents can be a potential cause of major catastrophes. About 60 percent of the total world oil production is transported by sea, and this percentage is very likely to increase in the future. The U.S. Coast Guard predicts that one out of every nine tankers will suffer an accident each year (Thompson, 1989). Other ways that oil can pollute waterways are: natural seepage, land drainage resulting from careless discharges of oily wastes from industrial operations, routine ship discharges from deballasting, bilge pumping, tank cleaning, oil transfer on vessel cargoes, and vessel grounding and collisions (Miller, 1974).

Inland oil spills not only result from natural seepage or land drainage from industrial operations, but also from storage tank overflows, pipeline leaks, broken sludge pond dikes, and inadequate waste disposal. Inasmuch as regulatory agencies and industries alike emphasize avoiding oil spills, no spill prevention scheme is yet fail-safe.

Chapter 3

Methodology

3.1 Location of Sampling Stations and Frequency of Sampling

Careful planning and implementation of water quality studies are necessary in optimizing the gathered information relative to study expenditures. An important element in planning a water quality study is the proper delineation of the objectives. Since this study is being funded by the U.S. Navy, the study objectives were mutually agreed upon between all concerned. Legal advise was obtained through the Navy Counsel to clarify any doubt on applicable regulations, instructions, and policies. Once the budget was allocated, the thesis objective was discussed with the Thesis Committee. Due to the time constraint imposed by the Navy to complete graduate program along with austere laboratory funds; the sampling duration, frequency of sampling and number of samples needed were limited. Start and stop dates were set with the Navy PWC Pearl Harbor Environmental Lab along with proper job order number and proper laboratory fee charges. Grab samples from each sampling station were collected and delivered weekly to the PWC Lab on Tuesdays to avoid any three-day weekend holidays, and prevent overloading laboratory personnel/technicians. Sampling kits are shown in Figure 4, and a copy of PWC Environmental Lab Sample Chain of Custody Form is shown in Appendix A.

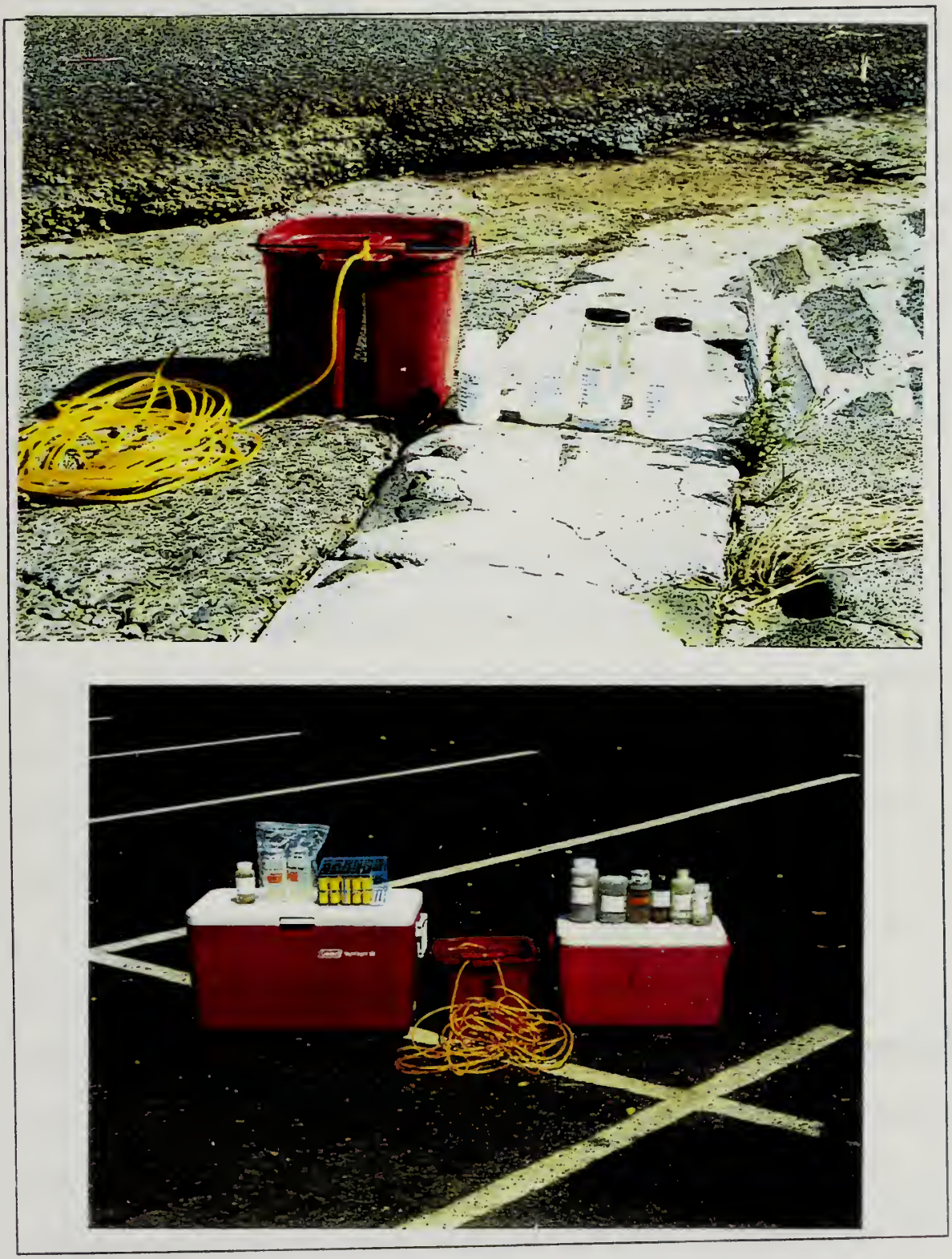


Figure 4. Sample Bottles, Bucket, and Coolers

3.1.1 Site Selection

A field reconnaissance of the pertinent study area is one of the most important phases of the baseline data gathering effort. A thorough reconnaissance provides the basis for the soundest possible study plan, insures smoother operation of the study, and also reduces confusion, time, effort, and cost in the long run. Elements that were considered during the site selection process include the availability of sampling equipment, accessibility, stream flow, and safety. Figure 3 shows the sampling site locations.

Site 1 is located inside the NAVMAG Waikele Branch. This is a restricted area, as such, base police provided escorts as needed. This site is on Kipapa Stream before merging with the Waikakalaua Stream. The elevation of the site is approximately 110 feet above mean sea level, and the streamflow is relatively constant except during heavy rains as shown in Figures 5 through 7.

Site 2, as shown in Figure 8 is also located at NAVMAG Waikele Branch. It is on Waikakalaua Stream before merging with Kipapa Stream. The U.S. Army property upstream of site 2 is currently leased for cattle grazing to a private firm. The elevation of site 2 is approximately 105 feet above mean sea level based on a Navy well located 600 feet downstream of the confluence of Kipapa Stream and Waikakalaua Stream with an elevation of 96 feet above mean sea level (Eyre, 1983).

Figure 5. Sampling Site Station 1

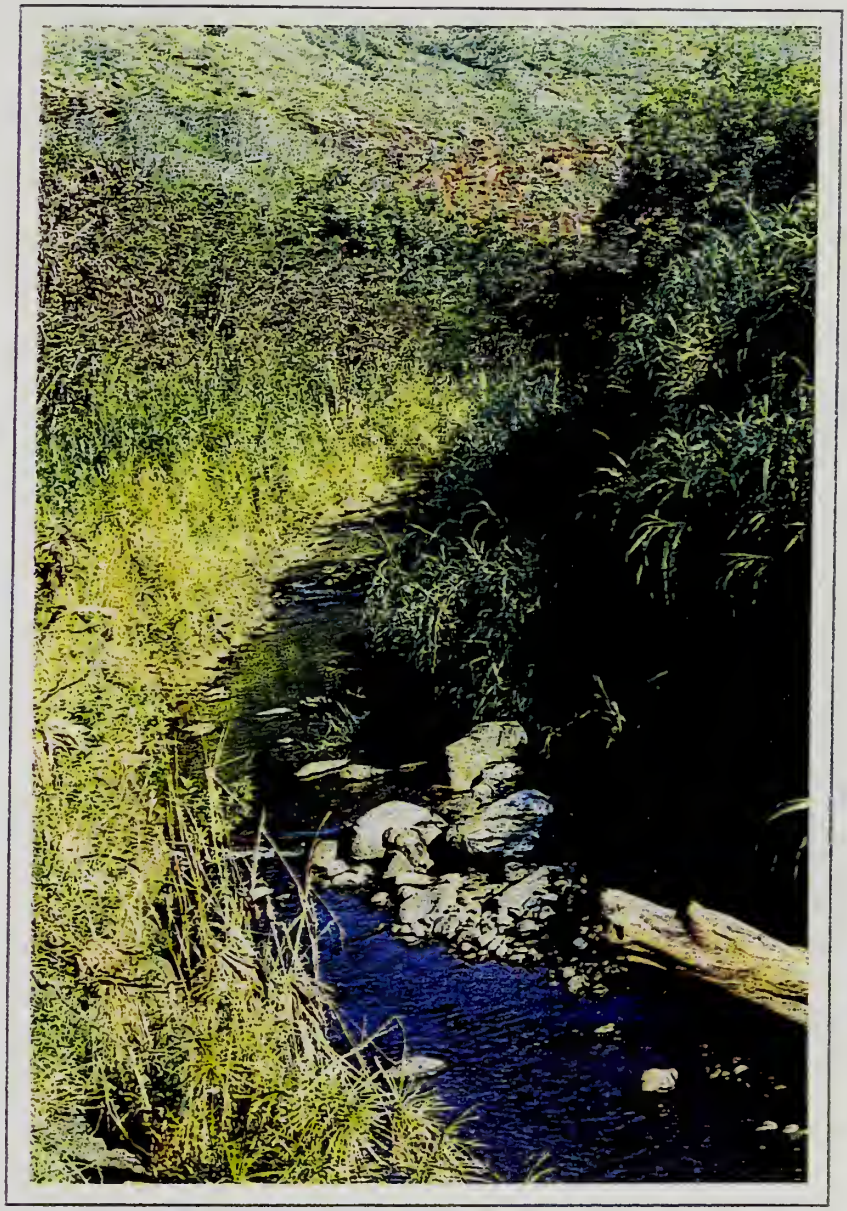


Figure 6. Upstream View from Sample Site Station 1

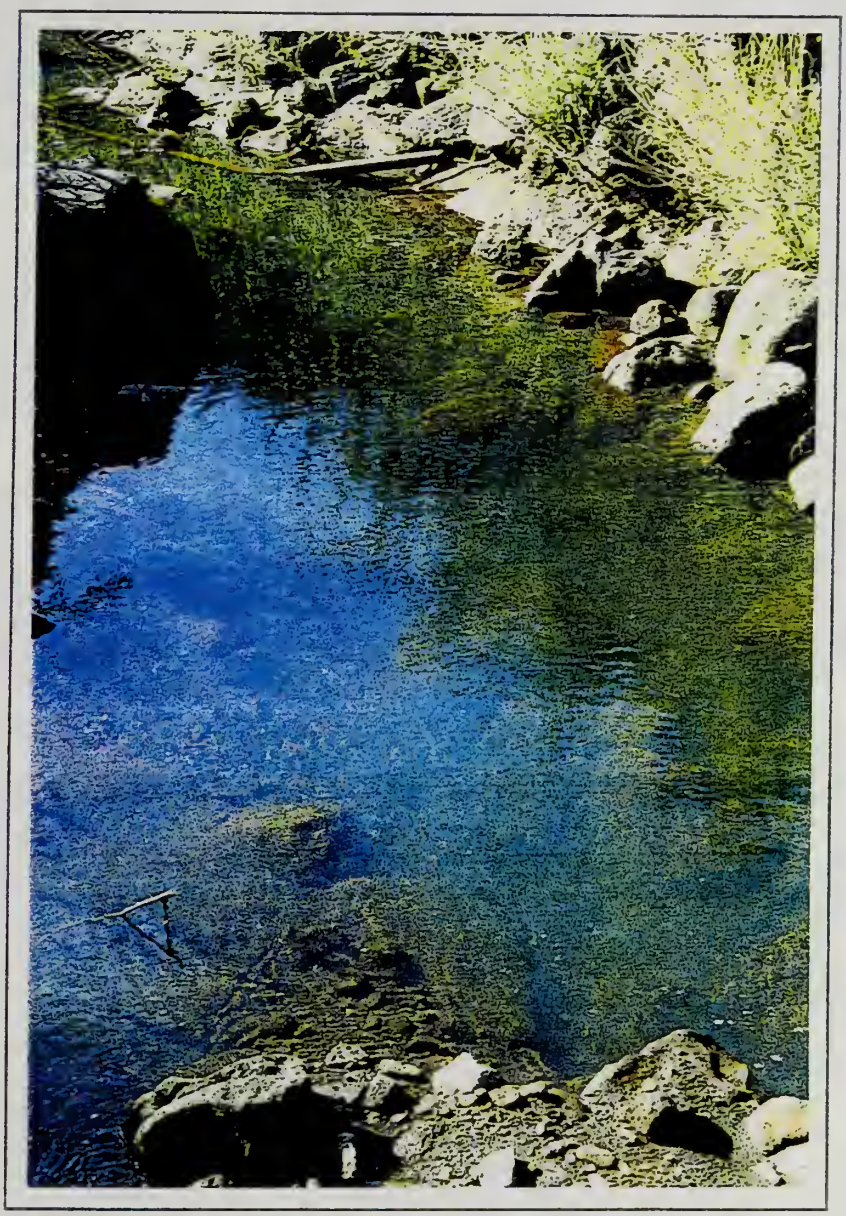


Figure 7. Downstream View from Sampling Site Station 1

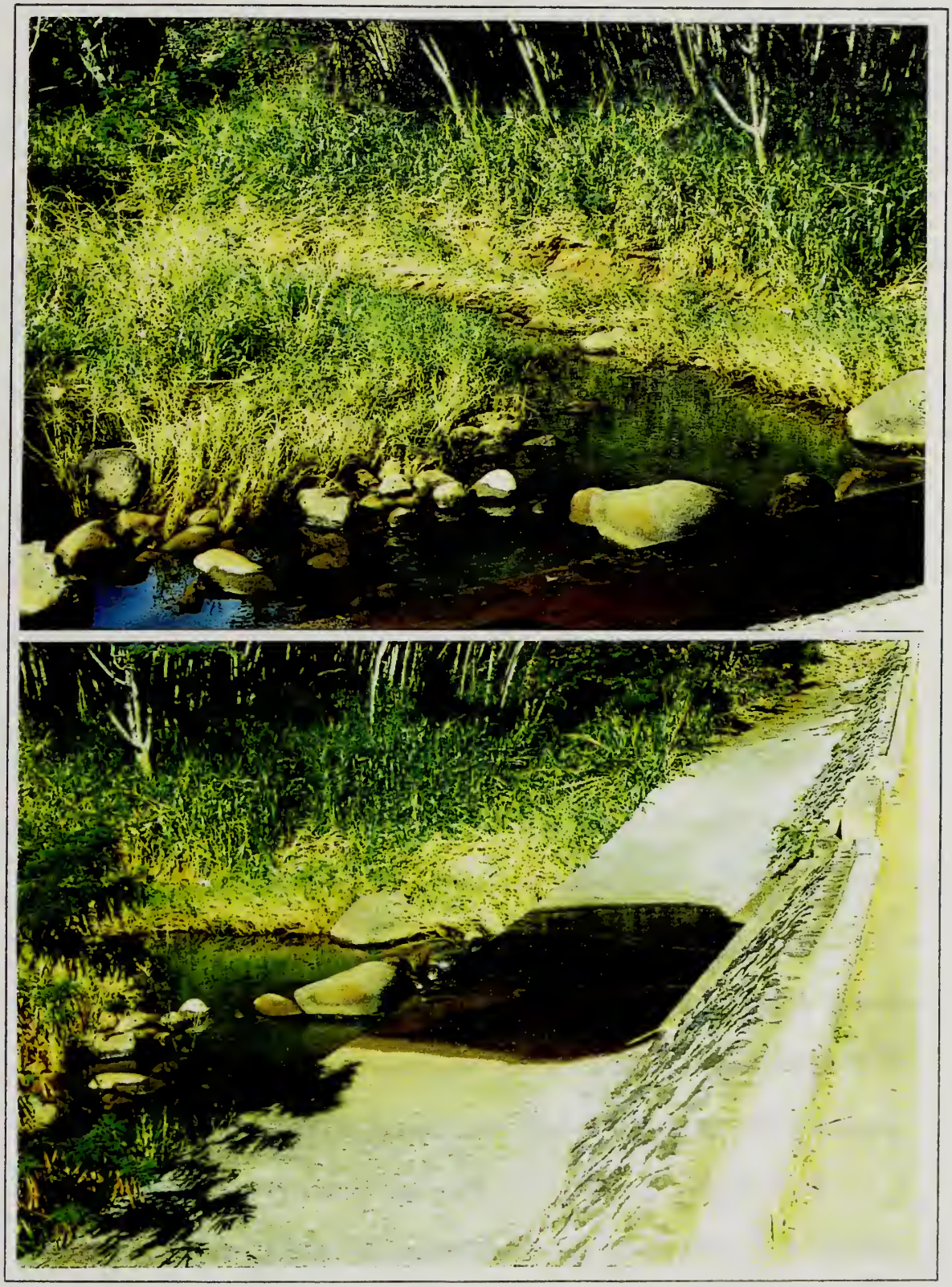


Figure 8. Sample Site Station 2

Site 3 is located downstream of the Oahu Sugar Company's (OSC) cane haul road under the H-1 Freeway (Figure 3). OSC's written consent and approval was required to use the cane haul road. As such, an access request letter was sent by the Navy. While waiting for OSC's response to the Navy's request for access, an alternate location just a few yards downstream was used without using OSC's cane haul road. This site was critical as it is the closest point after Kipapa Stream and Waikakalaua Stream confluence that is safely accessible. During the study period, the stream flow at this site appears to be relatively steady most of the time as shown in Figures 9 and 10. It was observed twice during the study period that when it rains hard, the stream water flows over the cane haul road. As shown in Figures 11 and 12, thick red sediments settle on the stream banks. These sediments will eventually flow back downstream with future rain and surface runoff.

Site 4 is located near Waipahu Street near the OSC mill (Figure 3). The south side of the stream between Sites 3 and 4 are lined with single family residential homes, while the other side is mostly a heavy growth of vegetation with some areas cultivated as small scale vegetable gardens. Figure 13 show the upstream view from site 4 with the stream flowing nearly full after heavy rains, and with the stream during normal condition. Figure 14 show downstream views from site 4 with stream flowing nearly full and during normal flow condition.

Figure 9. Sample Site Station 3

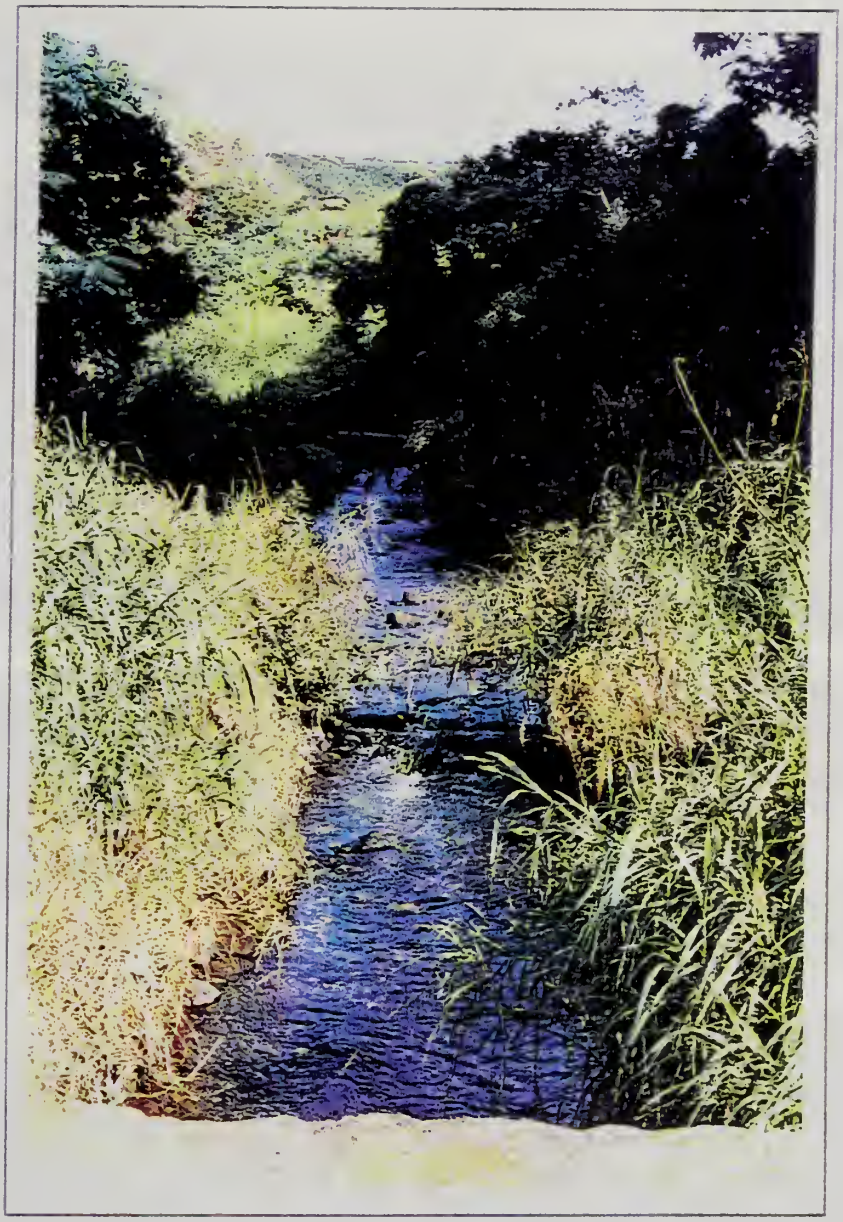


Figure 10. Upstream View from Sample Site Station 3

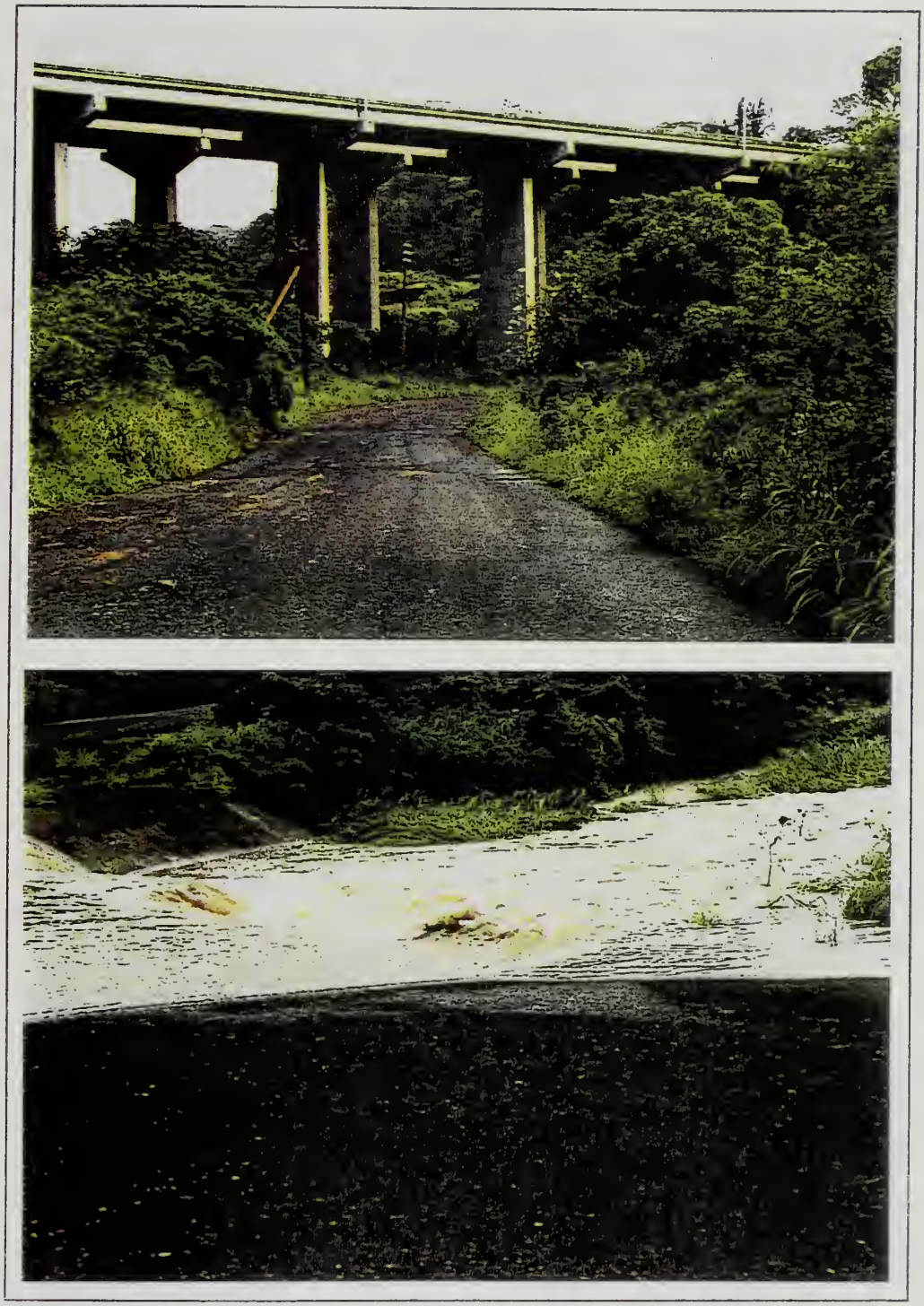


Figure 11. Access Road to Sample Site Station 3

Figure 12. Flooded Access Road to Sample Site Station 3

Figure 13. Upstream View from Sample Site Station 4

Figure 14. Downstream View from Sample Site Station 4

Site 5 is under a pedestrian overpass bridge located about 400 feet downstream of Farrington Highway at Waipahu (Figure 3). A USGS gaging station is located about 300 feet upstream of Farrington Highway and Waikele Spring is situated near the vicinity of the USGS gaging station. Taro and water cress farms are cultivated between sampling site stations 4 and 5. Waikele Spring is also located in the immediate vicinity. A few single family residential homes are also found along the stream banks between sites 4 and 5. Figures 15 through 17 show the upstream and downstream views of Waikele Stream from sample site station 5. The water at this site appears to be stagnant during normal dry weather conditions as shown in Figures 15 and 16. Some fish were sighted at this site during clear weather.

Site 6 is located at West Loch Estuary near the West Loch Estates subdivision and West Loch Municipal Park (Figure 3). There were numerous sightings of different fish species at this site along with clams and oysters. Some people were seen fishing from the fishing piers near the West Loch Municipal Park, and others were collecting clams and oysters. The tidal range was observed between zero to 2 feet. Except when it rains or during high winds, the water appears to be relatively clear. Figures 18 through 20 show a thick growth of mangrove around West Loch Estuary except in the vicinity of West Loch Municipal Park shoreline.

Figure 15. Upstream View from Sample Site Station 5

Figure 16. Downstream View from Sample Site Station 5

Figure 17. Downstream/Upstream Views from Sample Site Station 5

Figure 18. Sample Site Station 6

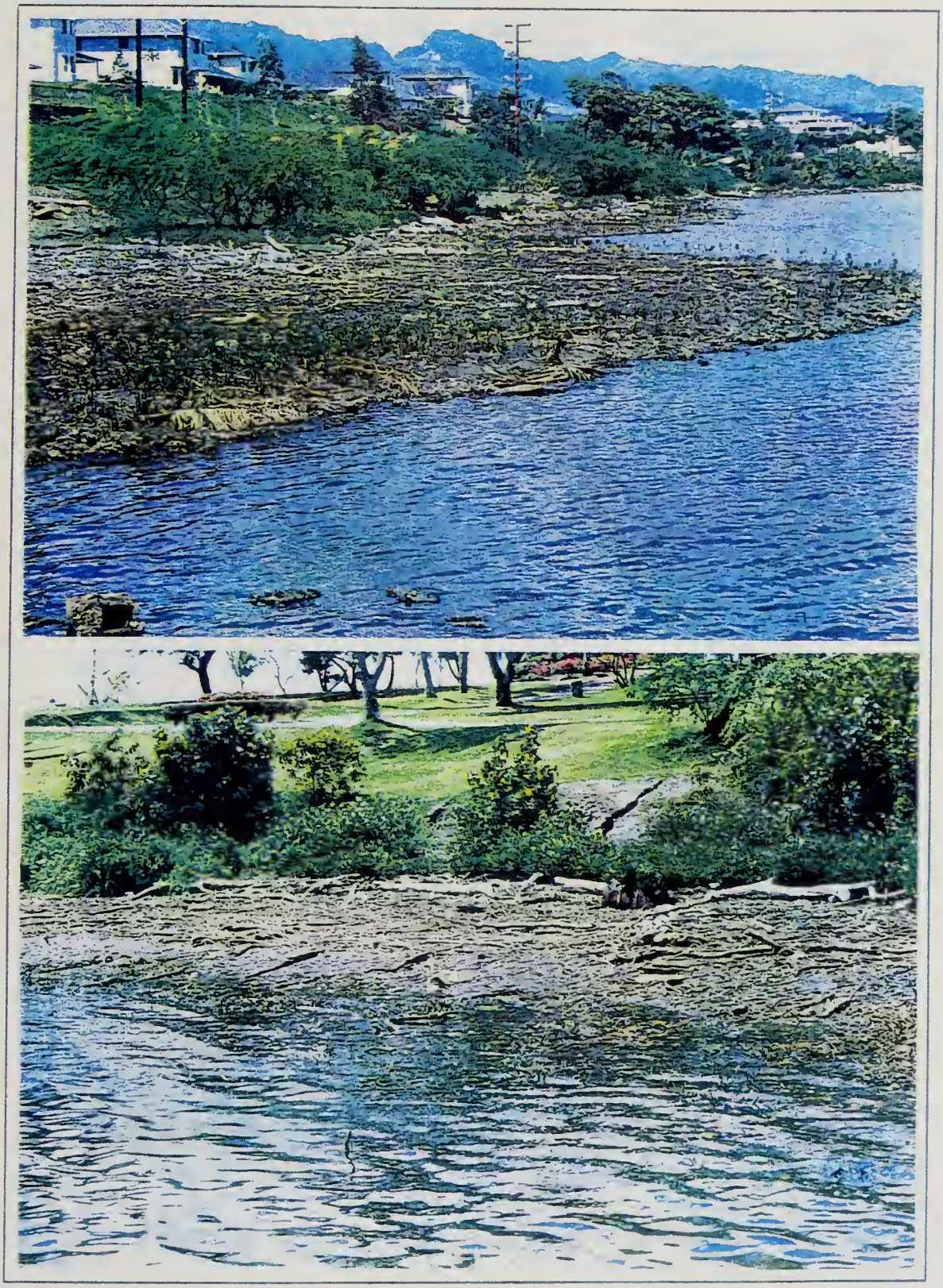


Figure 19. Sample Site Station 6 Shoreline

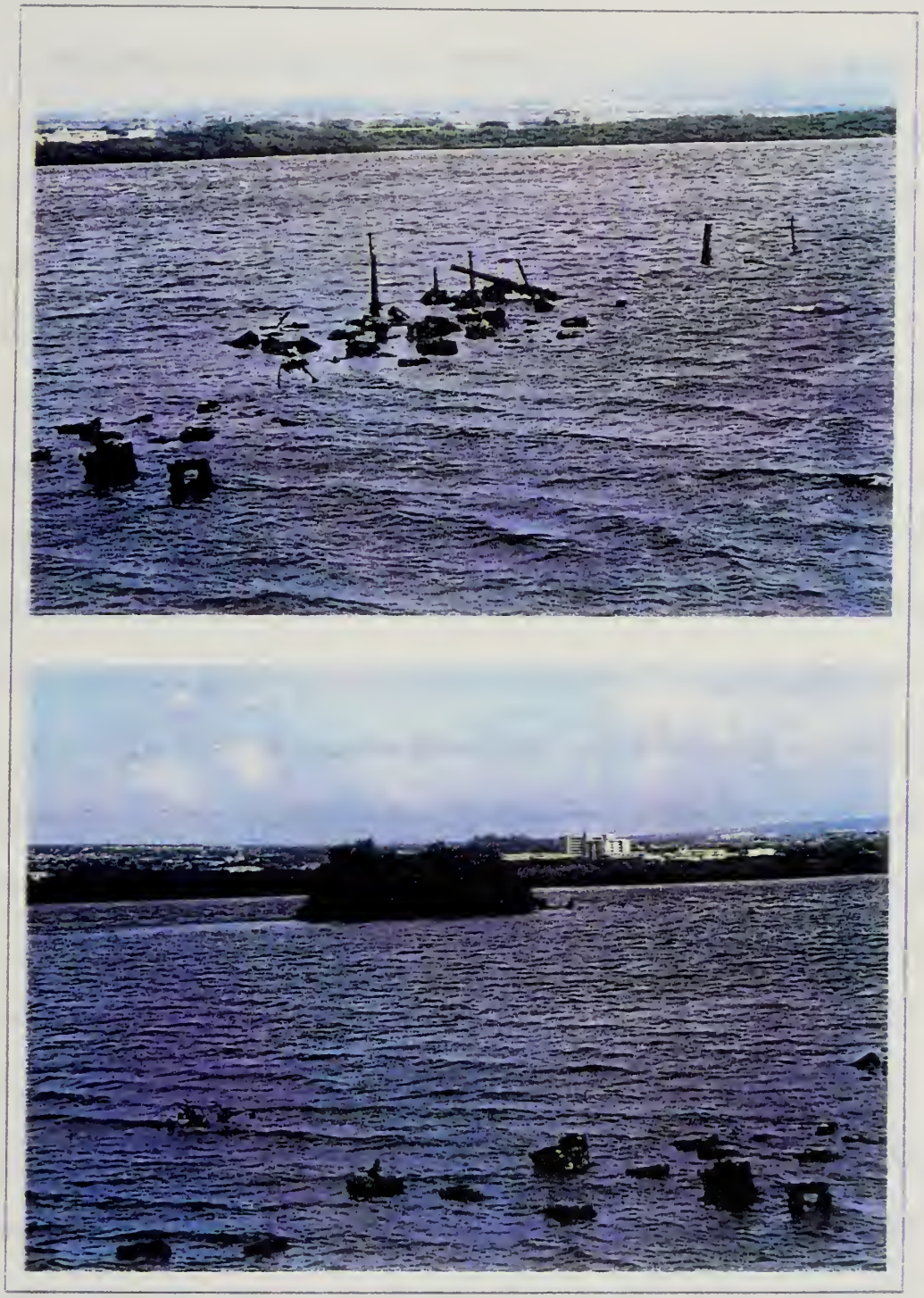


Figure 20. Sample Site Station 6 During High Winds

3.1.2 Number of Samples

The number of samples were based on the water quality parameter to be analyzed. As mentioned earlier, the allowed study timeframe was limited and the parameters selected to be analyzed were based on the availability of local laboratory resources, funds, and the current State of Hawaii DOH (1990) Water Quality Standards Chapter 11-54.

During the first two weeks (18 Feb 94 and 8 Mar 94) of sampling, there were 18 parameters tested. When the proper transfer and obligation of funds were made, along with PWC Pearl Lab concurrence, the number of parameters tested were increased by 11 to a total of 29 parameters which started on the week of 15 Mar 94 until 31 May 94.

One of the basic principles for consideration in sampling frequency identification is that increasing the number of samples will reduce the standard error of the mean value (Harbold, 1980). Since the standard error of the mean varies inversely as the square root of the number of observations, only a small gain is achieved by increasing the number of samples beyond the meaningful sufficient data for statistical analysis which is 18 to 24 samples (Ott, 1978). Again, this study was done with a limited time and funding. Only 14 weekly samples were collected, and analyzed. However, the 14 weekly samples should yield a reasonable mean, since the flow and temperature had little variations.

3.2 Test Methods

Most of the laboratory tests were done by PWC Pearl Harbor Environmental Lab except for COD and nutrients (i.e., ammonia, nitrite, nitrate, total organic N, and total phosphorus). The COD tests were contracted out to a private mainland consulting laboratory, while the nutrient analysis were contracted out to a private local consulting laboratory. Normally, these tests are conducted in-house, but due to the bi-annual Pacific Rim nations (RIMPAC) exercise in Hawaii, PWC Lab was tasked to provide priority support to the fleet.

In order to analyze the water quality parameters being monitored for Waikele Stream baseline study, the water constituents were grouped into physical, nutrient, organic, biological, inorganic, and pesticides. By doing so, the subsequent interpretation and management of data are much easier to organize and correlate (Canter, 1985).

3.2.1 Physical Water Quality Parameters

The physical water quality parameters that were monitored and analyzed are: pH, TSS, turbidity, and conductivity. Other physical quality parameters that are readily detectable include color, odor, and floating solids.

pH - is the negative logarithm of the hydrogen ion concentration, and it is a measure of acidity or alkalinity of water. Extreme levels of

either can imperil fish life and speed corrosion. A substance is acidic if its pH is < 7, basic if pH is > 7, and neutral if pH = 7. The pH scale runs from 1 (extremely acid) to 14 (strongly basic). It is known that water alkalinity has little public health significance but it is unpalatable when water has a high alkalinity content. pH can be adjusted or neutralized by using acid or alkalai additives. The pH of the grab water samples collected during this study was obtained by using a pH meter (Orion Ionalyzer, Model 601A). Another method being used is the Titration Method as outlined in Standards Methods (1992), 18th edition, Sections 2310 and 2320. The water analysis results are tabulated as shown in Table 4. The State of Hawaii DOH (1990) Water Quality Standards, Administrative Rules (Section 11-54) sets specific criteria for elevated wetlands, that pH shall not deviate more than 0.5 units from ambient conditions and shall not be lower than 4.5 nor higher than 7.

Total Suspended Solids - Suspended Solids (SS) is a portion of the Total Solids (TS) present in water. SS is also known as non-filterable residue. The other portion is Dissolved Solids (DS) or filterable residue that passes through a filter of 2.0 μm or smaller nominal pore size under specified conditions (DePinto et al., 1994). The basic difference between the two is that SS either float on the surface of, or are in suspension in water, wastewater, or other liquids, and which are largely removable by laboratory filtering. DS is theoretically the anhydrous residues of the

dissolved constituents in water (Canter, 1985). The TSS analysis for the grab water samples were performed by PWC Lab per Standard Methods (1992), 18th edition, Section 2540 D. The calculated results are tabulated as shown in Table 5. Per FWPCA, the minimum level of quality for SS is specified in terms of 30-day average values not to exceed 30 mg/L (West, 1993).

Turbidity - It applies to waters that contain dissolved or suspended matter that interferes with the passage of light or in which visual depth is restricted (Grace, 1978). Turbidity may be caused by clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, and other microscopic organisms. It is a measure of the optical property of light that causes it to be scattered and absorbed rather than transmitted through the sample.

Historically, turbidity was measured by using the Jackson Candle technique, which used a candle underneath a Nessler Tube calibrated in turbidity units. The lowest turbidity that could be measured was 25 Turbidity Units (Ambasht, 1990). In rivers and lakes, turbidity or transparency is measured by using a Secchi disk, which is a 200-mm disk with four quadrants, two blanks and two white, which is lowered into the water until it can no longer be seen. This is also a measure of the Euphotic zone in a lake (Krenkel et al., 1989). However, with the advent of modern technology, turbidity is now measured with a

nephelometer that registers the intensity of light scattered at 90 degrees to the path of the incident light. This is done by a comparison of the intensity of light scattered by the sample under defined conditions and with the intensity of light scattered by a standard reference suspension under the same conditions. The higher the intensity of scattered light, the higher the turbidity. Units are reported as Nephelometric Turbidity Units (NTU). Due to the association of turbidity with microorganisms, the EPA Maximum Contaminant Level Goal (MCLG) for turbidity in drinking water is zero (Pontius, 1992). However, the turbidity level in the State of Hawaii primary drinking water regulations is 1.0 NTU. The turbidity of the water samples for this study were measured with a Hach Turbidimeter (Model 16800).

Conductivity - Conductivity measurements have been used for decades for process control, especially in steam water plants, and for pollution abatement. It is the reciprocal of the resistivity, in ohm-centimeters, of a 1 centimeter cube of solution at a specified temperature. Water containing large amounts of phosphates, nitrates, ammonia, and potash conduct electricity, thus making their presence and relative quantities easily detectable. With continuous measurement, the information is immediately available and can be used as the basis for prompt corrective action. The ability of a solution to transmit a current depends primarily upon the number and type of ions the solution

contains. Conductivity depends on the presence of ions, their total concentration, mobility, valence and relative concentrations. It is also temperature dependent. Conductivity is reported in micro mhos per centimeter (μmhos/cm). In the SI system, conductivity is reported in millisiemans per meter (mS/m), where 1mS/m = 10μmhos/cm. The conductivity of freshly distilled water is 0.5 to 2 μmhos/cm, while that of most potable waters is from 50 to 1500μmhos/cm. Because of its ease and dependability of measurement, conductivity is quite useful in water quality investigations (Krenkel, 1989). The conductivity of the water samples for this study were analyzed with a Y.S.I. Conductivity Meter, Model 35.

3.2.2 Nutrient Water Quality Parameter

Nutrient enrichment, primarily due to nitrogen and phosphorus, is a major problem in many estuarine and some coastal marine systems. Excess nutrients can be highly damaging and can cause oxygen depletion, reduced fish and shellfish populations, nuisance algal booms, eutrophication dieback of seagrass, and corals (NRC, 1993). Estuaries receive more nutrient inputs per unit surface area than any other type of ecosystem. As such, nutrients should be considered a major ecological concern together with sewage disposal along many coastal areas, and should be regulated accordingly (EPA, 1993b).

The State of Hawaii DOH (1990) Water Quality Standards, Administrative Rules, Section 11-54, as mandated by the EPA, set specific criteria for streams and estuaries in Hawaii as shown in Tables 1 through 3.

Nitrogen - is a chemical element that occurs in nature mainly as a gas. It is a colorless, odorless gas at normal temperatures, and makes up about 78 percent of the earth's atmosphere (The World Book Encyclopedia, 1980). Lightning causes the nitrogen and oxygen in the air to form nitrogen oxide compounds. These oxides react with water to form nitric acid, which is carried to the earth dissolved in rainwater. Plants use these nitrogen oxide compounds to make protein. After the plants die and decay, the nitrogen compounds become part of the soil. As nitrogen is used and reused by living things, it goes through a continuous cycle of chemical changes. This cycle of changes is known as the nitrogen cycle (Sawyer et al., 1978).

Some nitrogen compounds contribute to the pollution of both water and air. The bacterial decomposition of organic fecal matter and the hydrolysis of urea found in urine form ammonia nitrogen. Depending on the pH of the solution, nitrogen can exists in aqueous solution as either the ammonium ion (NH_4+) or as ammonia (NH_3). Further bacterial action oxidizes the ammonia nitrogen to nitrite nitrogen (NO_2-N) and then nitrate nitrogen (NO_3-N). This process is called

Table 1 - Specific Water Quality Criteria for Streams in Hawaii

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than ten percent of the time	Not to exceed the given value more than two percent of the time
Total Nitrogen (μg N/L)	250.0 * 180.0 **	520.0 * 380.0 **	800.0 * 600.0 **
Nitrate+Nitrite Nitrogen (μg [NO3 + NO2] N/L)	70.0 * 80.0 **	180.0 * 90.0 **	300.0 * 170.0 **
Total Phosphorus (μg P/L)	50.0 * 30.0 **	100.0 * 60.0 **	150.0 * 80.0 **
Total Nonfilterable Residue (mg/L)	20.0 * 10.0 **	50.0 * 30.0 **	80.0 * 55.0 **
Turbidity (NTU)	5.0 * 2.0 **	15.0 * 5.5 **	25.0 * 10.0 **

* Wet Season - November 1 through April 30.

** Dry Season - May 1 through October 31.

Source: State of Hawaii DOH (1990) Water Quality Standards, HAR, Section 11-54.

Table 2 - Specific Water Quality Criteria for Pearl Harbor Estuary

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than ten percent of the time	Not to exceed the given value more than two percent of the time
Total Nitrogen (μg N/L)	300.00	550	750
Nitrate+Nitrite Nitrogen (μg [NO3 + NO2] N/L)	15	40.00	70.00
Ammonia Nitrogen (μg NH4-N/L)	10.00	20.00	30.00
Total Phosphorus (μg P/L)	60	130	200
Turbidity (NTU)	4.00	8	15

Source: State of Hawaii DOH (1990) Water Quality Standards, HAR, Section 11-54.

Table 3 - Specific Water Criteria for All Estuaries Except Pearl Harbor

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than ten percent of the time	Not to exceed the given value more than two percent of the time
Total Nitrogen (μg N/L)	200	350	500
Nitrate+Nitrite Nitrogen (μg [NO3 + NO2] N/L)	8	25	35
Ammonia Nitrogen (μg NH4-N/L)	6	10	20
Total Phosphorus (μg P/L)	25	50	75
Turbidity (NTU)	1.5	3	5

Source: State of Hawaii DOH (1990) Water Quality Standards, HAR, Section 11-54.

nitrification (Eckenfelder, 1989). A reverse process called denitrification returns an approximately equal amount of nitrogen back to the air. Nitrites are hardly found in nature because they are unstable and can be readily oxidized to nitrate form. The nitrates formed can be used as fertilizer for plants. However, excess nitrates that are not used by plant life are carried away in water by percolation which can increase the concentration of nitrates in the groundwater. It is known that excess nitrate content often caused methemoglobinemia in infants (blue babies). EPA requires that the nitrogen concentration in terms of nitrogen not exceed 10 mg/L in public water supplies (EPA, 1993a).

Free ammonia in concentrations above 0.2 mg/L can cause fatalities in several species of fish, but the National Academy of Sciences

applied a safety factor and recommended that no more than 0.02 mg/L free ammonia be permitted in receiving waters. Several methods can be used in determining the amount of nitrogen content in water. Distillation followed by titrimetric method per Standard Methods (1992), 18th edition, Sections 4500 NH3 B/E and 4500-Norg were used in determining the ammonia nitrogen and organic nitrogen content respectively. Total Kjeldahl-N was calculated as the sum of the ammonia-N and organic-N of the water samples. The Hach spectrophotometer was used to measure nitrite and nitrate nitrogen content of the water samples. Total N was calculated as the sum of the total Kjeldahl-N and nitrate+nitrite -N.

Phosphorus - is a chemical element that human beings, animals, and plants need for normal growth. Phosphorus is also used in the manufacture of many industrial products such as plant fertilizers. Plants absorb phosphorus compounds and human beings and animals eat the plants and other foods containing phosphorus. In the human body, phosphorus compounds are found chiefly in the bones, brain, and nerves. Red phosphorus is a brownish-red powder prepared by heating white phosphorus to a high temperature (250 degress Celcius). It is used in the manufacture of safety matches, pesticides, and smoke bombs.

Other phosphorus compounds are used in the production of steel, chinaware, and baking powder. The name *phosphorus* comes from a

Greek word which means *light bearer*. Phosphorus was discovered in 1669 by the German alchemist Hennig Brand. The chemical symbol for phosphorus is P with an atomic number 15 and atomic weight 30.973 (The World Book Encyclopedia, 1980). Phosphate metabolism is closely related to nitrogen metabolism and influence each other. Phosphorus is always found in traces in an oxidized state, like H_2PO_4, and HPO_4 in all natural waters, such as ground water, lakes, and rivers.

The ultimate source of phosphorus is the mineral matter of rocks. However, enough phosphorus reach water bodies around villages, towns and cities from the use of detergents, sewage/industrial effluents and agricultural fields runoff (Krenkel et al.). Despite being an essential element, phosphate enrichment of water beyond desired level is a very common feature and this can result in increased fertility, which can lead to rapid and lush growth of green and/or blue-green algae and macrophytes which cause choking of water bodies. The process of overfertility is known as eutrophication (Ambasht et al., 1992). Euthropic ponds emit foul smells due to excessive growth of decomposer organisms and putrefaction of dead algae, thus, exhausting dissolved oxygen. This is a serious kind of pollution because it can cause death of fishes and overall disuse of the ponds and lakes. Phosphorus may control primary production of algae in freshwater systems while nitrogen dominates saltwater system. The acceptable level of total inorganic

phosphate in water is 0.03 to 0.40 mg/L (NRC, 1993). The phosphorus content of the water samples for this study were tested as per Standard Methods (1990), 18th edition, Section 4500-P E.

3.2.3 Organic Water Quality Parameter

Most organic materials are attacked by bacteria and broken down into simpler compounds. Bacteria require oxygen to do this. The greater the supply of organic food, the larger the population of bacteria that can be supported, and the greater the demand on the oxygen in the water. This demand of oxygen by bacteria is called biochemical oxygen demand (BOD). BOD is an index of pollution, especially related to the organic load of the water. Since all stream animals depend on the oxygen supply in water, the BOD is of particular importance in determining which forms of life a polluted stream is capable of supporting.

Organic matter is a key to the eutrophication problem and carbon may often be more limiting than phosphorus. In natural streams and lakes, oxygen content is replenished by aeration through turbulent flows and waterfalls, and possibly by oxygenation of aquatic plants such as algae. Artificially, aeration of water is achieved by pumping air in water, or creating fountain sprays, such as in aquariums, hydroponic systems, and sewage treatment plants. Several processes are responsible for the depletion of dissolved organic oxygen. Part of the dissolved organic

compounds is sometimes referred to as dissolved organic carbon (DOC). Microbial decomposition of these organics consumes most of the dissolved oxygen. Moreover, a lack of O_2, rather than the presence of pollutants, may cause aquatic organisms to suffocate in polluted streams, lakes, and reservoirs (DePinto et al., 1994).

Biochemical Oxygen Demand (BOD_5) - is the amount of oxygen consumed by the microbial decomposition of organic matter during a 5-day incubation period . The test was developed in England, where it was considered that dissolved organic matter not decomposed within 5 days would be transported into the sea.(Tan, 1994). BOD test is a bioassay procedure that is widely used to determine the pollution strength of domestic and industrial waste, and measures what should happen in nature. From a regulatory standpoint, BOD is usually of primary interest for the control of effluent quality, especially for dischargers to streams or any freshwater bodies. EPA and State Regulating Agencies set minimum BOD_5 standards for secondary treatment requirement under the Clean Water Act for point source effluent discharge regardless of the quality of the receiving water.

The control of non-point sources of pollution that may contain high BOD is left primarily with the State through planning processes and National Pollution Discharge Elimination System (NPDES) permits. The 5-day BOD represents a different proportion of the total oxygen demand

for raw waste, as such, BOD is regulated on a weekly or monthly average for publicly owned treatment works (POTWs) and any single BOD does not represent a permit violation (West, 1993). The collected water samples were tested for BOD per Standard Methods (1992), 18th edition, Section 5210 B.

Chemical Oxygen Demand (COD) - is a measure of the oxygen-consuming capacity of inorganic and organic matter present in water or wastewater. It is expressed as the amount of oxygen consumed from a chemical oxidant in a specific test. However, it does not differentiate between stable and unstable organic matter and does not necessarily correlate with biochemical oxygen demand. Since COD is an oxidation-reduction reaction, other reduced substances, such as sulfides, sulfites, and ferrous iron will be oxidized and reported as COD. An advantage of the COD test is the short time required for evaluation. The COD test usually takes about three hours as compared to five days for the BOD test. The short time required to conduct the test allows a prompt corrective action to be done during the same day when any irregularity may occur. COD is more extensively used in industrial waste treatment facilities. The COD content of the collected water samples were tested by a private mainland consulting laboratory as per EPA Method 410.1. COD can sometimes be used as substitute for BOD since it usually correlates with BOD for specific waste (Cheremisinoff, 1993).

3.2.4 Biological Water Quality Parameter

Biological monitoring employs living organisms to indicate the presence of harmful chemicals in the environment. Through biological monitoring, early warning signs are detected and immediate action can be taken to repair the source of such chemicals. Biological monitoring also helps to identify the source of such pollutants and their pathway to human beings. By stopping the pollutants in their path, further damage to the environment and to human life can be avoided. Coliforms are bacteria residing normally in the intestinal tract of mammals. These are not necessarily dangerous but they are indicators of other possible pathogens (Lindeburg, 1992).

Bacteria are simple, single-cell (unicellular) organisms that use soluble food and are generally capable of self-reproduction without sunlight. Reproduction is by binary fission. Bacteria are so minute that they can be seen only through a microscope, as such they are also known as microorganisms. Bacteria occupy the lower intestines of humans and animals by the billions, and vast quantities of these bacteria pass out of the body with the feces. The average daily excrement of fecal matter per person in the United States is about twenty grams dry weight, of which approximately four or five grams are bacterial bodies, and about half are alive if the feces are fresh (Miller, 1974).

About ten percent are bacteria of the coliform group Escherichia

coli (E.coli). These are useful in the breakdown of organic materials, and with notable exception (recent E. Coli deaths due to eating inadequate cooked hamburger) almost all strains are essentially harmless to humans and animals. Some bacteria found in the lower intestines of humans are pathogenic. Such bacteria, when released into receiving waters can potentially infect others with diseases such as typhoid, cholera, paratyphoid, and dysentery. A newer trend segregate coliforms into total coliforms which are cultured at about 35 degrees Celcius, and fecal coliforms which are cultured at approximately 45 degrees Celcius (Kennish, 1994). Fecal coliforms are considered to be primarily composed of E.coli. The collected water samples were analyzed for fecal coliforms using the membrane-filter or multitube technique.

3.2.5 Inorganic Water Quality Parameter

Inorganic water quality parameters are chemical substances of mineral origin, and are not of basically carbon origin. The presence of inorganic contaminants in water continues to be one of the pervasive environmental issues. Some of the considered inorganic water quality parameters that were tested and analyzed for this study are: alkalinity, calcium, chlorides, copper, iron, lead, magnesium, manganese, mercury, potassium, sodium, and zinc. All the metal constituents except for mercury of the water samples collected for this study were analyzed with

an atomic absorption spectrophotometer Perkin-Elmer Model 5100, while an automated mercury analyzer Model PS200 by Leeman Laboratory was used in detecting for mercury content.

Alkalinity - is the capacity of water to neutralize acids. It is a property imparted by the water's content of carbonates, bicarbonates, hydroxides, and occasionally borates, silicates, and phosphates. It is expressed in milligrams per liter of equivalent calcium carbonate. Akalinity has little sanitary significance. However, the U.S. Public Health Service established standards on chemically treated waters, because high alkaline waters are usually unpalatable (Helweg, 1985). The determination of alkalinity provides an estimate of the alkaline constituents in water which can be used for corrosion control, water softening, and buffering capacity. If all the alkaline constituents are present as salts of calcium and magnesium, the alkalinity will equal the hardness. If the alkalinity is greater than the hardness, there are alkaline salts of metals other than calcium and magnesium present, generally, sodium or potassium salts. If the alkalinity is less than the hardness, there are salts of calcium or magnesium present that are not carbonates, which are usually sulfates or chlorides. An alkalinity of less than 100mg/L is desirable for water used for domestic purposes (Cheremisinoff, 1993). The collected water samples were tested for alkalinity per Standard Methods (1992), 18th edition, Section 2320 B.

Calcium (Ca) - is an element that belongs to the alkaline earth metal group. The primary sources of calcium are calcite, aragonite, dolomite and gypsum. Calcite is the major constituent of limestone. It is used as a dehydrating agent for organic chemicals, and as an adsorbent of gases in metallurgy and steel industry for making alloys with silicon. Calcium is often applied as a hardening material in cables and for the production of storage battery grids and bearings. It is a very important cation in lakes and streams. Calcium carbonate is insoluble in water, but will dissolve in water containing CO_2, a process called carbonation.

Chlorides - Chloride ions are among the most common anions found in some freshwater and in high abundance in all marine and coastal waters. All plants encounter chloride in nature and it is stored in animal bodies. As sodium chloride, it is beneficial to most organisms. The chloride anion moves freely from cell to cell via cytoplasm. It can also cause corrosion in concrete and metallic pipes to certain extent. If it is in the form of magnesium chloride, boiling water produces hydrochloric acid which causes severe corrosion (Ambasht et al., 1992).

Potable water may contain a small quantity of chloride without harmful effect (Sawyer et al., 1978). If chloride concentration is in the range of 200 mg/L or less, there is no salty taste, however, an objectionable salty taste may become detectable if the concentration exceeds 250 mg/L (Krenkel, 1989). Chloride is also an indicator of

sewage contamination inasmuch as urine contains 4260 to 4615 mg/L. Typical surface water has less than 10 mg/L while groundwater can contain chlorides approaching those of sea water due to saltwater intrusion and/or over pumping of aquifers without enough recharge (Cheremisinoff, 1993). Such intrusion has occurred at many locations in Florida and California.

Chlorides in natural water result from the leaching of chloride containing rocks and soils. In addition, agricultural, industrial, and domestic wastewaters discharged to surface waters are also a source of chlorides. Human excreta contain about six grams of chlorides per person per day (Metcalf & Eddy, 1972). In areas where hardness of water is high, the use of water softeners employing NaCl as the exchange media will also add large quantities of chlorides. Spray from the ocean being carried by wind forces inland as droplets or as minute salt crystals, which result from evaporation of the water in the droplets. This process constantly replenish the chlorides in inland areas where they fall. Agricultural water with chloride content less than 175 mg/L can be used to irrigate sensitive plants such as citrus, while water with chloride between 175 - 350 mg/L is considered medium, and water with chloride content greater than 350 mg/L can be used for sugar cane irrigation. High chlorides in sewage systems along the coast lines is not unusual due to infiltration/inflow during high tides, and heavy seas. The

collected water samples for this study were tested for chloride content as per Standard Methods (1992), 18th edition, Section 4500-Cl.

Copper (Cu) - occurs in the earth's crust at an average concentration of approximately 50 mg/kg, principally as a sulfide, both as the simple sulfide and in numerous sulfide minerals. Although the primary copper mineral is chalcopyrite ($CuFeS_2$), metallic copper and bornite are also economically important. Copper is essential in many enzymatic reactions in mammals. World production of copper in recent years has exceeded 8.5 million metric tons annually. The leading producers are Chile, USA, Russia, Canada, and Zambia. The major users are the USA, Russia, Japan, Germany, and China (Cordero, 1988).

Copper's usefulness as a metal is second only to that of iron. Modern uses include electrical wiring and electroplating, the production of alloys such as bronze and brass, antifouling paint, construction, plumbing, and ammunition shells. It is estimated that a total anthropogenic discharge of copper to surface waters range from 35 thousand to 90 thousand metric tons per year (Pacyna et al., 1988). The primary sources include domestic wastewater, manufacturing processes involving metals, steam electrical production, and from dumping of sewage sludge. Coastal marine waters are dominated by input from rivers, streams, dredging operations, and atmospheric sources.

Total copper can be detected in most freshwater at low

concentrations, generally less than 0.020 mg/L (Whitehead et al., 1988). Copper is highly toxic to most species of aquatic plants, and is routinely used as algicide and herbicide. Inhibition of growth generally occurs at concentrations less than 0.1 mg Cu/L, whereas chronic effects such as reduced carbon uptake may occur at concentrations in the 0.003 - 0.03 mg/L range (Hall et al., 1989). Depending on the water hardness, copper is one of the most toxic heavy metals to fish which ranges from 0.02 to 1.0 mg Cu/L in freshwater (Segner, 1987).

Iron (Fe) - is the third most abundant element in rocks and minerals. The central core of the earth is made up mostly of iron. All rocks, minerals, soils, and plants contain iron. In animals, it is present in the blood hemoglobin, which acts as a carrier of oxygen. Ferrous iron is the dominant iron species in ground water, where its concentration may range from 1.0 to 10mg/L. Dissolved iron at levels greater than 0.31 mg/L produces an unpleasant taste in drinking water (Tan,1994). It will also stain laundry and porcelain. Iron is needed only in trace amounts by plants, and animals. In some waters, it may limit the growth of algae.

Although iron is of little direct toxicologic significance, it often controls the concentration of other elements, including toxic heavy metals in surface water. The lethal concentration of iron to fish generally ranges from 0.3 to greater than 10 mg/L, depending on the species and

test conditions. Guidelines for the protection of aquatic life range from 0.3 to 1.0 mg Fe/L in many nations (Moore, 1991). Iron is found in most food, and is almost always detected in finished drinking water, simply because of its abundance in the earth's crust. A survey of the American Water Works Association in 1985, involving drinking water in 39 states and three territories, indicated that there were 2,200 episodes of non-compliance with the Maximum Contaminant Level of 0.3 mg/L (Moore, 1991). The primary concern about iron in drinking water is its objectionable taste. The taste of iron can be readily detected at 1.8 mg/L in drinking water and at 3.5 mg/L in distilled water (Cheremisinoff, 1993). High concentrations can also lead to massive growths of bacteria within the water systems.

Lead (Pb) - is the 36th most abundant element in the earth's crust, with an average concentration of 15 mg/kg. The input of anthropogenically derived lead to the environment now outweighs all natural sources, and is likely to remain so for the foreseeable future. Lead continues to be used in large amounts in storage batteries, metal products, pigments, and chemicals. Of these, storage batteries typically account for 60 percent of the total consumption in Western nations. Lead used in fuel has decreased drastically in recent years. It is emitted in large amounts from municipalities, both from the inceneration of waste products and the discharge of wastewater.

Total lead in surface water is highly variable, but is typically less than 0.05 mg/L. About 99 percent of the lead entering the oceans with the suspended load of rivers is deposited in the sediments of estuaries and continental shelves (Craig,1980). Inorganic lead is moderately toxic to aquatic plants. Under many test conditions, it is more toxic than chromium, manganese, barium, zinc, and iron, but is less toxic than cadmium, mercury, and copper. Lead is physiologically not a nutrient and its accumulation in soil may, therefore, cause pollution. It has been implicated in causing liver damage. However, no adverse effect has been reported by the intake of lead below the required threshold values (Tan, 1994).

Magnesium (Mg) - is an abundant metal in the earth's crust, and is the lightest metal that is used for building things. Manufacturers use magnesium alloys in building airplanes, guided missiles, electronic equipment, trucks, portable tools, furniture, ladders, and other equipment where light weight is important. It is also used to protect pipelines, underground storage tanks, and ship's hull from corrosion. Magnesium is abundant in seawater, and is available to most of the countries in the world. The average Magnesium content in soils is approximately 0.5 percent, whereas its concentration in water is about ten mg/L.

Manganese (Mn) - is the 11th most abundant element in the earth's crust, and one of the principal hardness-causing cations in water. Its primary use in the metal industry is to strengthen steel and to remove impurities like harmful oxygen from molten steel. About 95 percent of the manganese used in the United States goes into the production of steel. Pure manganese is seldom used commercially. Manganese oxide is used in dry-cell batteries to prevent polarization on the carbon electrode, while manganese sulfate is used in fertilizers to grow citrus fruits. It does not exist naturally in its pure state, because it reacts so easily with other elements.

Mercury (Hg) - is an element that has created a lot of concern among environmentalists. It is the only metal which is in a liquid state at room temperature. Because of its presence in the liquid state and its silvery luster, the metal is often called quicksilver. It exhibits a high boiling point and a uniform expansion and contraction. Therefore, mercury is an excellent substance for making thermometers, barometers and the like. All metals except iron will dissolve in mercury, including gold. Mercury vapor emits light, hence lead is also used in mercury vapor and fluorescence lamps. It is also useful in the production of explosives, detonators, and percussion caps.

Mercury and all mercury compounds are toxic in large amounts. However, in small amounts they are used in medicines. Concentration of

dissolved mercury is typically low in unpolluted freshwater, ranging from 10 to 100 ng/L, and in open ocean from less than 10 to 30 ng/L (Moore, 1991). A significant portion of mercury is associated with suspended solids, and accounts for a major part of the downstream transport of mercury in rivers. The typical Western diet yields approximately 0.015 mg Hg/day in a 70 kg (154 lbs.) reference man (Moore, 1991).

Mercury has caused more problems to the consumers of fish than any other iorganic contaminant. In extreme cases, consumption of mercury-tainted fish has led the onset of a serious neurological disease known as Minamata disease. In other cases, entire fisheries have been either restricted or significantly curtailed because of mercury contamination. Total mercury residues in drinking water are generally well below 0.005 mg/L, and essentially all of the water wells tested in the United States contained residues below 0.002 mg/L. The current drinking water guideline recommended by the World Health Organization for total mercury in several nations is 0.001 mg/L, whereas a guideline of 0.002 mg/L is in place in the United States (EPA, 1989).

Potassium (K) - is a silvery metallic element. It reacts readily with both oxygen and water. In nature, because of this characteristic, potassium always occurs combined with other elements. English chemist Humphry Davy, first isolated potassium as a pure metal in 1807. Potassium is the lightest metal except lithium. It is so soft that it

can be cut with a knife. It is a readily abundant element, and makes up nearly 2.5 percent of the earth's crust (Miller, 1974). Some potassium alloys are used in the heat transfer systems on some nuclear reactors. Plants require potassium for growth. Potassium chloride is widely used in commercial fertilizers for most plants. In animals, potassium helps in the process by which food changes into energy, and new tissue, known as metabolism (Kennish, 1992). Potassium as a metal is not usually used in determining the extend of water pollution, but is usually used in determining nutrients along with nitrogen, phosphorus, calcium, carbon, magnesium, and oxygen.

Sodium (Na) - is the sixth most common element in the earth's crust. Sodium never occurs pure as a separate element in nature. It combines with many other elements forming compounds. Sodium is also an alkali metal just as potassium, it is very reactive, and reacts vigorously with water, releasing hydrogen gas while producing at the same time the strong base NaOH. Sodium is used in industry as a reducing agent in the production of drugs, perfumes, and dyes. It is used for making sodium lights, which produce yellow light that penetrates dense fog. These lights are frequently used for automobile headlights and streetlights. Sodium is generally less reactive than potassium. Sodium reacts rapidly with chloride to form NaCl (table salt), which can accumulate in arid regions or where drainage is

inhibited. NaCl contributes toward the development of salinity, resulting in a decrease in the quality of soil and water (Tan, 1994).

Zinc (Zn) - is the 24th most common elementin the earth's crust. The major uses of zinc are in coatings to protect iron and steel, and for die casting. The total amount of zinc discharged to freshwaters from anthropogenic sources is estimated between 77 thousand to 373 thousand metric tons per year (Pacyna et al., 1988). Other major sources are from the discharge of domestic wastewater, coal-burning power plants, manufacturing process involving metals, and atmospheric fallout. Total zinc discharges to coastal and estuarine waters have declined during the latter half of this century, reflecting the implementation of sound waste control practices (Moore, 1991).

Zinc is routinely detected in drinking water, reflecting its presence in raw water and dissolutiion of solder and other material in the distribution system. It is not considered carcinogenic in humans or experimental animals. Zinc also poses no significant toxicologic threat to drinking waters. The drinking water guideline is based on aesthetic factors, particularly taste and appearance. Although it is important to monitor zinc residues in drinking waters, there is no need to establish a toxicologically based guideline. However, a survey done by AWWA in 1985, revealed 10 cases of non-compliance with the MCL of 5 mg/L (Moore, 1991).

3.2.6 Pesticides

Pesticides are a major health risk water quality parameter since their use is directly related in crop production to control pests and diseases in plants. Pesticides include: insecticides, fungicides, nematocides, rodenticides, and herbicides. Their potential as a pollutant depends on their biodegradability and toxicity to animals and people. Pesticides that can persist in soils for a long time affect the food chain by a process called biological magnification, meaning accumulation and subsequent concentration in the food chain. Persistence of pesticides is often expressed in terms of half-life. which is the length of time required for one-half of a given amount of the pesticide to disappear or decompose to other compounds. DDT, a chlorinated hydrocarbon widely used during World War II as an insecticide, is banned today because of its persistence in soils and its toxicity to animals and humans. The principal degradation product of DDT, called DDE, is also persistent, and has been implicated for the development of thin eggshells in birds. Aldrin, another common pesticide at the time of DDT use, yields a decomposition product called dieldrin which is reported to be more toxic than aldrin (Ware, 1983).

The pesticides that were monitored for this study were based on the potential pollutants anticipated from waste discharges considering the geographic land use and development adjacent to Waikele Stream.

Five potential pesticides were monitored, namely: heptachlor, lindane, endrin, methoxychlor, and toxaphene. The collected water samples were analyzed for these pesticides concentration as per EPA Method 505, Micro-extraction Technique. All five pesticides tested were non-detectable (ND) as shown in Table 4.

Heptachlor - is mostly used for residual control of subterranean termites, and a few agricultural uses.

Lindane - has many uses including seed treatment, and moderate fumigant action.

Endrin - is used for mouse control in orchard, for cotton insect control, and a few other crops.

Toxaphene - is an amazing mixture of more than 177 polychlorinated derivatives, ten of which are carbon compound constituents. Toxaphene had by far the greatest use of any single insecticide in agriculture.

Methoxychlor - is widely used on fruit and shade trees, vegetables, home gardens, and livestock (Ware, 1983).

Chapter 4

Results and Discussions

All the obtained results are tabulated as shown in Table 4. In order to have a meaningful comparison, the obtained results' geometric mean for each of the parameters monitored per site is calculated as:

$$\text{geometric mean} = (x_1 x_2 x_3 \ldots x_n)^{1/n}.$$

The calculated geometric means, along with corresponding variances and standard deviations are tabulated in Table 5. The partial listing of water quality parameters for Waikele Stream before the Mililani WWTP ceased discharging effluent into Waikele Stream in 1986 are tabulated in Table 6. The calculated results were compared with the State of Hawaii Water Quality Standards DOH (1990) Administrative Rules, Section 11-54, as tabulated in Tables 1 through 3, and 1973 West Loch water quality parameters as tabulated in Table 7.

4.1 Site 1

This site shows an improvement in the water quality parameters that were monitored and tested except for the total nitrogen, which is on the borderline for wet season criteria. This site is the most upstream site on Kipapa Stream, located inside the Navy base at NAVMAG Lualualei Waikele Branch. The high fecal coliform count may be from animal feces coming from the leased Army land located upstream of this site.

Table 4 - Water Sample Analysis Results

Sample Date	18 Feb 94						8 Mar 94					
Sample Site No.	1	2	3	4	5	6	1	2	3	4	5	6
pH	7.22	7.29	7.31	7.24	7.35	7.69	7.59	7.33	7.55	7.32	7.33	8
Conductivity (µmho)	78	61	98	128	209	9,980	134	124	332	364	962	38,500
Chloride (mg/L)	120	90	150	185	360	3,430	13	11	57	56	230	16,000
Alkalinity (mg/L)	17	13	21	26	32	59	39	41	59	68	61	112
COD (mg/L)	5	4	5	5	4	8	4	broken	4	3	3	4
TSS (mg/L)	3.4	7.4	8.8	9.4	6.6	16	0.8	2.4	2.8	2.2	2.6	36
NH3-N (mg/L)	0.11	0.01	0.01	0.04	0.08	0.62	0.06	0.04	0.02	0.04	0.02	0.24
Total Organic N (mg/L)	0.22	0.14	0.14	0.21	0.21	0.83	0.18	0.17	0.15	0.16	0.17	0.51
Total Kjeldahl N (mg/L)	0.33	0.16	0.14	0.25	0.29	1.45	0.24	0.21	0.17	0.2	0.19	0.75
NO2/NO3-N (mg/L)	0.12	0.17	0.21	0.04	0.6	0.3	0.18	0.05	0.48	1.46	1.36	0.11
Total N (mg/L)	0.45	0.33	0.35	0.29	0.89	1.75	0.42	0.26	0.65	1.66	1.55	0.86
Total P (mg/L)	0.02	0.02	0.05	0.02	0.09	0.1	0.01	0.02	0.04	0.21	0.2	0.08
Fe (mg/L)	0.2	0.3	0.3	0.3	0.3	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	0.06
Na (mg/L)	7.4	5.5	8.4	12.8	23.4	1,840	9	8.5	24.6	41.5	124	7,950
K (mg/L)	0.8	0.63	0.73	0.92	1.28	62	1.03	1.74	1.63	1.84	4.65	272
Ca (mg/L)	3.3	2.9	4.6	5.4	7.5	310	7.8	6	14.4	10.8	14	320
Mg (mg/L)	2.1	1.3	2.7	3.1	4.6	1,970	4.1	2.9	9	7.9	16	915
Cu (mg/L)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.06
Zn (mg/L)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Mn (mg/L)	<0.05	<0.05	0.05	0.05	0.07	0.21	<0.05	<0.05	<0.05	<0.05	<0.05	0.07
Pb (mg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2

Table 4 - Water Sample Analysis Results (continued)

Sample Date	15 Mar 94						22 Mar 94					
Sample Site No.	1	2	3	4	5	6	1	2	3	4	5	6
pH	7.69	7.51	7.48	7.27	7.34	7.75	7.97	7.64	7.63	7.41	7.38	7.78
Conductivity (µmho)	143	123	318	356	1,417	44,300	276	127	295	345	919	39,400
Chloride (mg/L)	16	12	54	57	55	19,000	52	15	54	57	242	18,000
Alkalinity (mg/L)	44	41	70	68	61	120	48	42	59	70	64	129
COD (mg/L)	15	4	4	3	3	9	5	3	5	2	4	6
TSS (mg/L)	0.6	1.8	3	2	3	350	3.4	3.8	2	1.8	2.6	75
NH3 (mg/L)	0.08	0.07	0.06	0.05	0.1	0.19	0.02	0.05	0.12	0.04	0.1	0.2
Total Organic N (mg/L)	0.18	0.19	0.16	0.11	0.2	2.07	0.35	0.2	0.23	0.38	0.12	0.79
Total Kjeldahl N (mg/L)	0.26	0.25	0.23	0.16	0.3	2.26	0.37	0.25	0.35	0.43	0.21	0.99
NO2/NO3 (mg/L)	0.01	0.04	0.45	1.43	1.33	0.16	0.01	0.04	0.39	1.34	1.35	0.34
Total N (mg/L)	0.27	0.29	0.68	1.59	1.63	2.42	0.38	0.29	0.74	1.77	1.56	1.33
Total P (mg/L)	0.02	0.02	0.05	0.19	0.21	0.69	0.04	0.02	0.04	0.17	0.2	0.19
Fe (mg/L)	<0.1	0.2	<0.1	<0.1	<0.1	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	0.3
Na (mg/L)	9.6	8.8	25.2	37.6	192	9,630	36	9.6	23.2	38.5	118	8,810
K (mg/L)	0.98	0.9	1.59	1.74	6	342	2.16	0.93	1.57	1.83	4.05	314
Ca (mg/L)	8.6	8.5	15	10.8	17	390	11.4	7.8	14.4	12	16	380
Mg (mg/L)	5	3.7	9.7	8.6	25.6	1,110	9	3.9	9.7	9.3	19.3	1,020
Cu (mg/L)	<0.05	<0.05	<0.05	<0.05	<0.05	0.06	<0.05	<0.05	<0.05	<0.05	<0.05	0.08
Zn (mg/L)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Mn (mg/L)	<0.05	<0.05	<0.05	<0.05	<0.05	0.26	<0.05	<0.05	<0.05	<0.05	<0.05	0.14
Pb (mg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	0.2
Hg (mg/L)	n/a	n/a	n/a	n/a	n/a	n/a	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Fecal Coli (No./100ml)	n/a	n/a	n/a	n/a	n/a	n/a	300	500	100	500	690	100
BOD5 (mg/L)	n/a	n/a	n/a	n/a	n/a	n/a	<2.0	<2.0	2	<2.0	<2.0	<2.0
Turbidity (NTU)	n/a	n/a	n/a	n/a	n/a	n/a	3.3	4.4	1.8	1.3	1.4	8.2
Heptachlor	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Lindane	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Endrin	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Metoxychlor	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Toxaphene	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D

ND = None Detectable

Table 4 - Water Sample Analysis Results (continued)

Sample Date	29 Mar 94						5 Apr 94					
Sample Site No.	1	2	3	4	5	6	1	2	3	4	5	6
pH	7.65	7 6	7.53	7 52	7.49	7 83	7 55	7 5	7 48	7 35	7 31	7 89
Conductivity (µmho)	79	84	102	124	214	21,000	134	96	148	226	848	32,700
Chloride (mg/L)	14	12	17	20	40	8,000	26	14	25	42	239	14,600
Alkalinity (mg/L)	14	23	20	25	32	80	27	41	43	48	52	109
COD (mg/L)	3	4	3	4	3	4	3	3	3	3	2	3
TSS (mg/L)	7 8	4 8	3 2	5 8	4 4	37	0 2	1 6	2 6	1 4	2	200
NH3 (mg/L)	0 04	0 01	0 01	0 01	0 01	0 15	0 02	0 04	0 08	0 15	0 06	0 17
Total Organic N (mg/L)	0 09	0 08	0 07	0 11	0 12	0 39	0 09	0 12	0 19	0 29	0 18	1 28
Total Kjeldahl N (mg/L)	0 13	0 09	0 07	0 13	0 13	0 54	0 12	0 16	0 27	0 45	0 24	1 45
NO2/NO3 (mg/L)	0 06	0 09	0 06	0 25	0 46	0 2	0 03	0 02	0 12	0 67	0 88	0 011
Total N (mg/L)	0 19	0 17	0 13	0 37	0 59	0 74	0 14	0 18	0 39	1 12	1 12	1 461
Total P (mg/L)	0 01	0 02	0 01	0 04	0 06	0 06	0 01	0 02	0 03	0 1	0 13	0 38
Fe (mg/L)	0 1	0 1	0 2	0 1	0 1	1 1	0 1	0 2	0 2	0 2	0 2	5 1
Na (mg/L)	6 8	6 7	8 7	11 4	21 8	4,400	13 2	7 6	11 9	22 8	116	7,500
K (mg/L)	0 66	0 62	0 71	0 81	6 1	126	0 94	0 72	1 02	1 35	4 53	260
Ca (mg/L)	3	4 5	4 6	5 4	7 4	160	5 6	6	8 7	10	14 4	320
Mg (mg/L)	2 5	2 8	3 2	3 6	5 4	475	4 5	3 3	5 2	6 6	18 3	845
Cu (mg/L)	<0 05	<0 05	<0 05	<0 05	<0 05	<0 05	<0 05	<0 05	<0 05	<0 05	<0 05	0 06
Zn (mg/L)	<0 05	<0 05	<0 05	<0 05	0 06	0 24	<0 05	<0 05	<0 05	<0 05	<0 05	<0 05
Mn (mg/L)	<0 05	<0 05	<0 05	<0 05	<0 05	<0 05	<0 05	<0 05	0 06	0 06	0 08	0 39
Pb (mg/L)	<0 1	<0 1	<0 1	<0 1	<0 1	0 1	<0 1	<0 1	<0 1	<0 1	<0 1	0 1
Hg (mg/L)	<0 005	<0 005	<0 005	<0 005	<0 005	<0 005	<0 005	<0 005	<0 005	<0 005	<0 005	<0 005
Fecal Coli. (No /100ml)	7,000	6,600	1,200	1,000	2,600	200	720	170	250	3,800	1,400	<40
BOD5 (mg/L)	<2 0	<2 0	<2 0	<2 0	<2 0	2 2	< 2	< 2	< 2	< 2	< 2	3 4
Turbidity (NTU)	7 6	12	8 6	8 8	7 4	3 2	1 8	9	6 5	4 5	3 2	8 7
Heptachlor	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Lindane	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Endrin	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Metoxychlor	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Toxaphene	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D

ND = None Detectable

Table 4 - Water Sample Analysis Results (continued)

Sample Date	12 Apr 94						19 Apr 94					
Sample Site No.	1	2	3	4	5	6	1	2	3	4	5	6
pH	7.76	7 58	7 46	7.36	7 28	7.66	7.43	7 55	7 44	7 28	7 22	7 61
Conductivity (µmho)	177	75	111	126	1,170	25,500	118	84	120	142	964	34,000
Chloride (mg/L)	41	12	20	22	352	2,000	26	12	20	22	349	2,974
Alkalinity (mg/L)	23	23	46	32	40	104	16	25	29	33	40	113
COD (mg/L)	4	4	6	8	7	7	5	7	1	13	6	broken
TSS (mg/L)	6.4	7 2	7.4	6 4	6 8	41 8	2 4	18 4	9 8	9	7 4	63 5
NH3 (mg/L)	0.06	0.03	0.06	0 05	0 1	0 28	0 01	0 04	0 03	0 05	0 05	0 25
Total Organic N (mg/L)	0.16	0 14	0 22	0 22	0 29	0 71	0 15	0 19	0 18	0 22	0 3	1 01
Total Kjeldahl N (mg/L)	0 22	0 16	0 29	0 28	0 39	0 99	0 16	0 23	0 21	0 27	0 34	1 26
NO2/NO3 (mg/L)	0 05	0 03	0 08	0 28	0 5	0 17	0 01	0 04	0 15	0 37	0 51	0 2
Total N (mg/L)	0 27	0 19	0.36	0.56	0 89	1 16	0 17	0 27	0 36	0 63	0 85	1 46
Total P (mg/L)	0.06	0 03	0 05	0.07	0 1	0 12	0 01	0 06	0 05	0 08	0 1	0 18
Fe (mg/L)	0 8	0 3	0.4	0.2	<0.1	0 1	0 3	0 7	0 5	0 4	<0 1	0 2
Na (mg/L)	30 6	6 6	9 2	13 4	194	6,000	14	7 6	10 7	15 4	144	7,900
K (mg/L)	1 44	0 5	0 72	0 87	5 35	164	0 68	0 42	0 62	0 74	4 53	230
Ca (mg/L)	6 4	4 2	5 7	6 3	14	230	3 4	4 7	6 3	6 2	12 8	320
Mg (mg/L)	5 3	2 5	3 4	4	23 3	635	3	2 7	3 7	4 1	18 6	850
Cu (mg/L)	<0 05	<0 05	<0.05	<0 05	<0 05	<0 05	<0 05	<0 05	<0 05	<0 05	<0 05	0 05
Zn (mg/L)	<0 05	<0.05	<0.05	<0 05	<0 05	<0.05	<0 05	<0 05	<0 05	<0 05	<0 05	<0 05
Mn (mg/L)	<0 05	<0 05	<0.05	<0.05	<0.05	0 13	<0 05	<0 05	<0 05	<0 05	<0 05	0 05
Pb (mg/L)	<0 1	<0.1	<0.1	<0 1	<0.1	0 1	<0 1	<0.1	<0 1	<0 1	<0 1	0 2
Hg (mg/L)	<0.005	<0.005	<0 005	<0.005	<0.005	<0 005	<0 005	<0 005	<0 005	<0.005	<0 005	<0.005
Fecal Coli. (No./100ml)	2,800	710	1,800	1,700	1,600	180	2,600	680	1,700	1,700	1,000	170
BOD5 (mg/L)	<2 0	<2 0	<2.0	<2 0	<2.0	2.7	<2 0	<2 0	<2 0	<2.0	<2 0	<2 0
Turbidity (NTU)	39	15	25	21	16	6 3	8	25	21	19	13	8 8
Heptachlor	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Lindane	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Endrin	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Metoxychlor	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Toxaphene	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D

ND = None Detectable

Table 4 - Water Sample Analysis Results (continued)

Sample Date	26 Apr 94						3 May 94					
Sample Site No.	1	2	3	4	5	6	1	2	3	4	5	6
pH	7.45	7.59	7.39	7 37	7.35	7.65	7 71	7 72	7 48	7 41	7 36	7 5
Conductivity (µmho)	98	91	155	169	1,358	32,900	93	100	172	200	457	34,500
Chloride (mg/L)	17	12	26	27	425	2,874	15	11	27	31	105	2,910
Alkalinity (mg/L)	23	34	38	42	50	138	23	33	40	45	50	126
COD (mg/L)	5	3	3	3	4	6	<1	3	3	3	4	<1
TSS (mg/L)	3.2	11.2	5.2	3 6	3.2	52	0 4	7	3 8	3	3 8	51
NH3 (mg/L)	0 05	0.039	0.04	0.083	0.045	0 224	0 004	0 006	0 016	0 016	0 024	0 245
Total Organic N (mg/L)	0.244	0.166	0.148	0.185	0 105	0.751	0 092	0 193	0 285	0 39	0 26	0 93
Total Kjeldahl N (mg/L)	0.294	0 205	0.188	0.268	0 15	0 975	0 096	0 199	0 301	0 406	0 284	1 175
NO2/NO3 (mg/L)	0 007	0 004	0 162	0.46	0 722	0.092	0 003	0 005	0 234	0 62	0 847	0 254
Total N (mg/L)	0 301	0.209	0.35	0.728	0 872	1 067	0 099	0 204	0 535	1 026	1 131	1 429
Total P (mg/L)	0 011	0.027	0 027	0.066	0 109	0.108	0 1	0 021	0 021	0 078	0 121	0 018
Fe (mg/L)	1 2	0 3	0.1	0 2	<0.1	0 1	0 05	0 17	0 17	0 12	0 15	0 78
Na (mg/L)	9	7 3	11 8	17 4	224	6,500	9 8	9 3	16 8	20 4	48	6,600
K (mg/L)	0 62	0 45	0.59	0.79	7 6	230	0 97	0 61	1 14	1 53	3	316
Ca (mg/L)	4 8	5 7	7 5	8	16	310	3 2	3 9	6 03	5 15	7 03	248
Mg (mg/L)	3 2	3 2	4 1	4 9	27 2	845	3 03	3 57	5 66	5 87	10 05	787
Cu (mg/L)	<0.05	<0 05	<0.05	<0 05	<0.05	0.05	<0 05	<0 05	<0 05	<0 05	<0 05	<0 05
Zn (mg/L)	<0 05	<0 05	<0 05	<0 05	<0 05	<0.05	<0 05	<0 05	<0 05	<0 05	<0 05	0 05
Mn (mg/L)	<0.05	<0.05	<0.05	<0 05	<0.05	0.05	<0 05	<0 05	0 05	0 05	0 06	0 13
Pb (mg/L)	<0 1	<0 1	<0 1	<0 1	<0.1	0 2	<0 05	<0 05	<0.05	<0 05	<0 05	0 15
Hg (mg/L)	<0 005	<0 005	<0.005	<0 005	<0 005	<0.005	0 005	<0 005	<0 005	<0 005	<0 005	<0 005
Fecal Coli. (No./100ml)	1,600	270	250	280	250	50	1,200	100	980	330	340	46
BOD5 (mg/L)	<2 0	<2.0	<2.0	<2 0	<2.0	2	<2 0	<2 0	<2 0	<2 0	<2 0	<2 0
Turbidity (NTU)	26	12	9 7	9 2	6.3	5.4	3 2	19	9	9 1	7 7	11
Heptachlor	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Lindane	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Endrin	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Metoxychlor	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Toxaphene	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D

ND = None Detectable

Table 4 - Water Sample Analysis Results (continued)

Sample Date	10 May 94						17 May 94					
Sample Site No.	1	2	3	4	5	6	1	2	3	4	5	6
pH	7.84	7.81	7 57	7.45	7 33	7 62	7 77	7.87	7 61	7 41	7 38	7 58
Conductivity (µmho)	110	106	230	247	900	38,500	139	116	212	245	469	25,600
Chloride (mg/L)	14	15	40	41	249	3,749	26	15	36	40	110	3,324
Alkalinity (mg/L)	37	31	50	56	68	117	12	39	47	54	55	122
COD (mg/L)	4	5	5	4	2	5	1	<1	1	<1	1	<1
TSS (mg/L)	14 2	0.8	4.2	2.2	3	144	0 4	9	5 4	3	2 8	31 8
NH3 (mg/L)	0.43	0.39	0.132	0 059	0.053	0.247	0 124	0 076	0.04	0 038	0 037	0 217
Total Organic N (mg/L)	0.19	0.2	0.393	0 218	0 2	1	0 649	0 367	0 333	0 258	0 245	0 623
Total Kjeldahl N (mg/L)	0 62	0.59	0.525	0.277	0 253	1 247	0 773	0 443	0 373	0 296	0 282	0 84
NO2/NO3 (mg/L)	0.006	0 005	0 413	0 847	1.06	0.036	0 11	0 002	0 375	0 842	1 03	0 214
Total N (mg/L)	0.626	0.595	0.938	1 124	1 313	1 283	0 883	0 445	0 748	1 138	1 312	1 054
Total P (mg/L)	0 2	0 005	0 033	0 112	0 153	0 336	0 013	0 033	0 026	0 107	0 146	0 118
Fe (mg/L)	0 27	<0 05	0 15	0.13	0 1	1 72	0 08	0 35	0 24	0 16	0 16	0 38
Na (mg/L)	7 4	4 8	17 4	26 4	116	6,600	10 6	7 8	18 4	23 6	47	6,500
K (mg/L)	0 63	0.88	1 48	1.53	5.7	392	1 39	0 83	1 44	1 67	3	378
Ca (mg/L)	4 16	4 07	7 47	6 24	9.03	360	3 86	4.53	6 51	7 1	5 9	351
Mg (mg/L)	3 78	4 02	7 57	7 25	18.3	1,010	3 9	3 83	6 85	8 5	6 6	921
Cu (mg/L)	<0 05	<0 05	<0 05	<0 05	<0 05	0 05	<0 05	<0 05	<0 05	<0 05	<0 05	<0 05
Zn (mg/L)	<0 05	<0 05	<0 05	<0 05	<0 05	0 05	<0 05	<0 05	<0 05	<0 05	<0 05	<0 05
Mn (mg/L)	<0 05	<0 05	0 06	0 05	0 05	0 29	<0 05	<0 05	<0 05	<0 05	<0 05	0 1
Pb (mg/L)	<0 05	<0 05	<0 05	<0 05	<0 05	0 16	<0 05	<0 05	<0 05	<0 05	<0 05	0 16
Hg (mg/L)	<0 005	<0 005	<0 005	<0 005	<0 005	<0 005	<0 005	<0 005	<0 005	<0 005	<0 005	<0 005
Fecal Coli. (No./100ml)	480	780	400	460	240	8	300	500	500	720	300	10
BOD5 (mg/L)	<2 0	<2 0	<2 0	<2 0	<2 0	<2 0	<2 0	<2 0	3 5	<2 0	<2 0	<2 0
Turbidity (NTU)	21	1 9	12	10	7 7	13	2 2	24	12	9	7 2	3 8
Heptachlor	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Lindane	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Endrin	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Metoxychlor	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Toxaphene	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D

ND = None Detectable

Table 4 -Water Sample Analysis Results (continued)

Sample Date	24 May 94						31 May 94					
Sample Site No.	1	2	3	4	5	6	1	2	3	4	5	6
pH	7.64	7.72	7.15	7.36	7.22	7.67	7.97	7.8	7.56	7.39	7.3	7.58
Conductivity (µmho)	153	100	190	202	2,250	35,000	119	101	153	188	460	35,600
Chloride (mg/L)	34	14	31	34	702	3,124	24	10	25	31	114	3,525
Alkalinity (mg/L)	26	34	51	50	50	109	25	41	32	49	52	124
COD (mg/L)	4	2	3	2	2	6	<5	6.2	5.2	7.5	6.2	130
TSS (mg/L)	1.2	50	17	11	10	130	1	11	4.6	4.4	4.6	70
NH3 (mg/L)	0.017	0.021	0.011	0.021	0.031	0.16	0.034	0.022	0.021	0.019	0.024	0.124
Total Organic N (mg/L)	0.216	0.273	0.247	0.233	0.27	1.28	0.349	0.203	0.218	0.3	0.197	0.91
Total Kjeldahl N (mg/L)	0.233	0.294	0.258	0.254	0.301	1.44	0.383	0.225	0.239	0.319	0.221	1.034
NO2/NO3 (mg/L)	0.005	0.011	0.28	0.642	0.883	0.152	0.008	0.008	0.172	0.542	0.75	0.238
Total N (mg/L)	0.238	0.305	0.538	0.896	1.184	1.592	0.391	0.233	0.411	0.861	0.971	1.272
Total P (mg/L)	0.006	0.035	0.03	0.085	0.114	0.311	0.026	0.041	0.036	0.089	0.121	0.198
Fe (mg/L)	0.22	0.54	0.3	0.22	0.18	1.74	0.12	0.31	0.22	0.17	0.14	0.94
Na (mg/L)	23	4.6	16	17	321	7,000	11.4	6.2	11.6	23.8	36	6,600
K (mg/L)	2.24	0.67	1.54	1.52	16.5	298	1.44	0.52	0.85	1.24	3	390
Ca (mg/L)	4.16	3.93	5.86	5.26	15.8	320	3.65	4.1	4.72	5.23	6.59	339
Mg (mg/L)	5.63	3.49	6.24	5.53	44.7	862	3.64	3.57	4.52	5.77	10.15	891
Cu (mg/L)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Zn (mg/L)	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Mn (mg/L)	<0.05	0.05	0.06	<0.05	0.05	0.25	<0.05	<0.05	<0.05	0.05	0.05	0.13
Pb (mg/L)	<0.05	<0.05	<0.05	<0.05	<0.05	0.16	<0.05	<0.05	<0.05	<0.05	<0.05	0.17
Hg (mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Fecal Coli (No /100ml)	2,500	560	1,300	1,300	560	35	840	40	1,000	2,800	300	150
BOD5 (mg/L)	<2	<2	<2	<2	<2	3.4	2.1	<2	<2	<2	<2	<2
Turbidity (NTU)	5.2	26	21	16	10	12	4	26	17	16	12	7.1
Heptachlor	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Lindane	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Endrin	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Metoxychlor	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Toxaphene	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D

ND = None Detectable

Table 5 - Calculated Water Quality Parameter Geometric Means
(February - May 1994)

Site No.	1	2	3	4	5	Mean	Variance	Std.Dev	6
pH	7.66	7.61	7.47	7.37	7.33	7.5	0.017	0.13	7.53
Conductivity (µmho/cm)	110	97	174	163	739	257	59,052	243	30,326
Chloride (mg/L)	25	14	3,434	39	255	753	1,804,333	1,343	5,330
Alkalinity (mg/L)	25	31	41	45	49	38	79	8.9	109
COD (mg/L)	4	3	3.2	3.6	3.2	3.4	0.13	0.34	5
TSS (mg/L)	1.7	5.7	4.8	3.8	4	4	1.8	1.3	66.5
NH3 (mg/L)	0.04	0.03	0.06	0.06	0.07	0.05	0	0.014	0.251
Total Organic N (mg/L)	0.19	0.166	0.196	0.22	0.195	0.193	0	0.017	0.862
Total Kjeldahl N (mg/L)	0.23	0.196	0.256	0.28	0.265	0.25	0.001	0.03	1.113
NO2/NO3 (mg/L)	0.02	0.18	0.214	0.53	0.824	0.35	0.08	0.29	0.138
Total N (mg/L)	0.25	0.376	0.47	0.81	1.089	0.6	0.09	0.3	1.251
Total P (mg/L)	0.02	0.02	0.03	0.08	0.13	0.06	0.002	0.04	0.15
Fe (mg/L)	0.17	0.212	0.19	0.19	0.16	0.18	0	0.17	0.66
Na (mg/L)	12.19	7.04	14.27	21.19	86.61	28.3	872	29.5	4,554
K (mg/L)	1.04	0.69	1.04	1.25	4.59	1.7	2.09	1.45	245
Ca (mg/L)	4.8	4.87	7.31	7.08	10.91	7	4.9	2.2	304
Mg (mg/L)	3.92	3.1	5.36	5.75	14.76	6.6	17.7	4.2	895
Cu (mg/L)	<0.05	---	---	---	---	---	---	---	---
Zn (mg/L)	<0.05	---	---	---	---	---	---	---	---
Mn (mg/L)	<0.05	---	---	---	---	---	---	---	---
Pb (mg/L)	<0.05	---	---	---	---	---	---	---	---
Hg (mg/L)	<0.005	---	---	---	---	---	---	---	---
Fecal Coli. (No./100ml)	1,184	416	626	956	607	758	75,574	275	57.7
BOD5 (mg/L)	<2.0	<2.0	<2.0	<2.0	<2.0	---	---	---	---
Turbidity (NTU)	6.7	12.6	10.8	9.2	7.1	9.3	5	2.2	5.8
Heptachlor	ND	ND	ND	ND	ND	---	---	---	ND
Lindane	ND	ND	ND	ND	ND	---	---	---	ND
Endrin	ND	ND	ND	ND	ND	---	---	---	ND
Metoxychlor	ND	ND	ND	ND	ND	---	---	---	ND
Toxaphene	ND	ND	ND	ND	ND	---	---	---	ND

ND - None detectable

Table 6 - Waikele Stream Water Quality Data (1976 - 1985)

Year	76	77	78	79	80	81	82	83	84	85	Mean	Variance	Std. Dev.
pH	---	---	---	---	7 3	7 2	7 3	7 4	7 4	7 5	7 35	0 009	0 096
Conductivity (µmho)	322	442	289	462	329	302	369	488	449	427	388	5,446	73 8
Chloride (mg/L)	61	78	46	79	58	51	62	102	71	88	70	303	17 4
Alkalinity (mg/L)	---	---	---	---	---	---	---	---	---	---	---	---	---
COD (mg/L)	---	---	---	---	---	---	---	---	---	---	---	---	---
TSS (mg/L)	13	13	92	42	86	225	151	3	6	7	64	5,640	75 1
NH3 (mg/L)	2 95	---	0 17	1 04	0 2	0 04	---	---	---	0 39	0 8	1 04	1 02
Total Organic N (mg/L)	0 65	---	0 85	0 66	0 83	1 11	---	---	---	0 19	0 72	0 096	0 31
Total Kjeldahl N (mg/L)	3 6	0 73	1 02	1 7	1 03	1 15	1 16	1 6	0 54	0 58	1 3	0 792	0 89
NO2/NO3 (mg/L)	0 4	---	3 08	3 3	1 57	2 25	---	---	---	1 6	2 03	1 17	1 08
Total N (mg/L)	4	4 2	4 1	5	2 6	3 4	---	---	---	2 2	3 6	0 96	0 98
Total P (mg/L)	---	---	---	71	47	---	---	---	---	---	4 3	---	---
Fe (mg/L)	0 4	0 9	2 8	0 5	0 5	1 9	0 6	---	---	---	1 1	0 85	0 92
Na + K (mg/L)	---	---	---	71	47	---	---	---	---	---	59	289	17
Ca (mg/L)	9 3	11 1	10	12	8 2	8 2	10 4	14 1	11 5	12 8	10 8	3 72	1 93
Mg (mg/L)	7 2	9 2	5 9	9 5	9 5	6 1	7 6	11 9	9	11	8 7	3 92	1 98
Cu (mg/L)	0 02	0 015	0 011	0 006	0 004	0 007	0 006	---	---	---	0 01	0	0 006
Zn (mg/L)	0 02	0 14	0 02	0 02	0 01	0 02	0 013	---	---	---	0 03	0 003	0 05
Mn (mg/L)	0 08	0 1	0 12	0 13	0 9	0 12	0 08	---	---	---	0 22	0 09	0 3
Pb (mg/L)	0 2	0 2	0 28	0 05	0 004	0 003	0 002	---	---	---	0 11	0 014	0 12
Hg (mg/L)	<0 005	<0 005	<0 005	<0 005	<0 005	<0 005	<0 005	---	---	---	<0 005	---	---
Fecal Coli. (No /100ml)	43,825	14,210	47,850	25,780	28,390	6,100	5,000	25,800	10,400	33,500	24,086	226,653,025	15,055
BOD5 (mg/L)	---	---	---	---	---	---	---	---	---	---	---	---	---
Turbidity (NTU)	---	---	17 6	4 5	8 2	12 3	6 4	1 3	3 8	3 8	7 2	29 2	5 4
Heptachlor	0	0	0	0	0	0	0	0	0	0	---	---	---
Lindane	0	0	0	0	0	0	0	0	0	0	---	---	---
Endrin	0	0	0	0	0	0	0	0	0	0	---	---	---
Metoxychlor	0	0	0	0	0	0	0	0	0	0	---	---	---
Toxaphene	0	0	0	0	0	0	0	0	0	0	---	---	---

Source: USGS, (1976-1986) and USGS, (1994)

Table 7 - West Loch Water-Quality Parameters (1973)

Parameter	Range	Surface Mean	Range	Bottom Mean
Turbidity (JTU)	1.3-9.0	3.7	1.5-40.0	6.2
Secchi Disc (m)	0.1-2.5	1.2	N/A	N/A
Salinity (ppt)	16.1-35.4	30.7	32.0-37.3	35.3
Dissolved Oxygen (ppm)	3.8-9.0	7.3	0.1-5.8	2.8*
Total Phosphorus (ppm)	Neg.-0.21	0.11*	Neg.-0.21	0.07*
Total Kjeldahl Nitrogen (ppm)	Neg.-0.2	0.12	Neg.-0.23	1.15
Total Organic Carbon (ppm)	1.0-10.5	4.7	Neg.-8.0	2.8
Total Coliform (MPN/100 ml)	10-30000	175	N/A	N/A
Fecal Coliform (MPN/100ml)	10-15000	1390*	N/A	N/A

Source: NAVFAC (1973)

* Not acceptable for Class A waters per Section 11-54 of the State of Hawaii DOH (1990) Water Quality Standards

4.2 Site 2

This site is on Waikakalaua Stream, about 200 feet upstream of the confluence point of Kipapa and Waikakalaua Streams. This site also has an improvement in the water quality except for total nitrogen, which is beyond the threshold of 0.25 mg/L during wet season, and 0.180 mg/L during dry season. TSS is higher than site 1, due to ongoing development along the Waikakalaua Stream. The Royal Kunia golf course and Royal Kunia Phase II housing development were currently in progress during the study period. Another factor in the increase of the total nitrogen level is the cattle grazing outlease upstream.

4.3 Site 3

This site is located downstream of the Oahu Sugar Company's (OSC) cane haul road under the H-1 Freeway. The test results show an improvement except again for total nitrogen and chloride. It is not known where the chloride may come from. This site has almost a steady flow and the water is not stale. There are single family homes on both sides of the stream between this site and the confluence point of Waikele Stream as well as ongoing development in the Waikele Shopping Area. A golf course is also located at this site, with the storm run-off leading to Waikele Stream. As evidenced by Figures 11 and 12, the turbid water during heavy rains carry along thick sediments that will eventually end up at West Loch.

4.4 Site 4

This site is located under the Waipahu Street Bridge near the Waipahu Sugar Mill. All the parameters tested show an improvement except for total nitrogen. The area between this site, and site 3 has some small scale vegetable gardening along the stream banks. There are also single family housing units on the south side of the stream. Typically, the waterflow at this site remains fairly steady, except during heavy rains. This site is a choke point for the Waikele Stream drainage shed.

Figures 13 and 14 show both a calm weather condition, and a turbulent flow condition during heavy rains.

4.5 Site 5

This site is located under a pedestrian bridge downstream of Farrington Highway, near Waipahu Intermediate School. This is where the estuary and the stream meet. Depending on the tides and weather, the water at this site remains mostly calm. As such, the water is stagnant and piles of debris accumulate just downstream of the overpass. As evidenced by the test results, this is where the conductivity, chloride, magnesium, sodium, and calcium increase.

A comparison of the the obtained water quality parameters geometric mean for sites 1 through 5 and the USGS (1976-1985) water quality mean data are shown as tabulated in Table 8. Since the USGS gaging station along Waikele Stream is just upstream of site 5, Table 8 was developed to compare the latest obtained laboratory analysis with the USGS data from Table 6. The comparison reveals that most of the water quality parameters on Waikele Stream have significantly improved except for pH, chloride, and turbidity. The cessation of effluent discharge from the Mililani WWTP into Waikele Stream since 1986 improved stream water quality. The rise in chloride content is mainly due to the location of site 5, which is affected by tides.

Table 8 - Sites 1 to 5 and USGS Water Quality Parameter Means

Parameter Mean		1976 - 1985	Feb - May 1994
pH		7.35	7.5
Conductivity	(µmho/cm)	388	257
Chloride	(mg/L)	70	753
TSS	(mg/L)	64	4
NH3	(mg/L)	0.8	0.05
Total Organic N	(mg/L)	0.72	0.193
Total Kjeldahl N	(mg/L)	1.3	0.25
NO2/NO3	(mg/L)	2.03	0.35
Total N	(mg/L)	3.6	0.6
Total P	(mg/L)	4.3	0.06
Fe	(mg/L)	1.1	0.18
Na + K	(mg/L)	59	30
Turbidity	(NTU)	7.2	9.3
Ca	(mg/L)	10.8	7
Mg	(mg/L)	8.7	6.6
Fecal Coliform	(No./100ml)	24,086	758

Table 9 - Site 6 and West Loch Water Quality Parameter Means

Parameter Mean	1973 Surface Mean	Feb - May 1994
Turbidity	3.7 (JTU)	5.8 (NTU)
Secchi Disc (m)	1.2	---
Salinity	30.7 (ppt)	5,330 (mg/L)
Dissolved Oxygen	7.3 (ppm)	---
Total Phosphorus	0.11 (ppm)	0.15 (mg/L)
Total Kjeldahl Nitrogen	0.12 (ppm)	1.113 (mg/L)
Total Organic Carbon	4.7 (ppm)	0.862 (mg/L)
Fecal Coliform	1,390 (MPN/100ml)	57.7 (No./100ml)

4.6 Site 6

This site is on West Loch Estuary near the West Loch Municipal Park. This location was selected as the safest, and most accessible area close to the mouth of Waikele Stream. There are thick mangroves surrounding West Loch except near the park.

As expected, the water samples resemble a typical estuarine water quality. TSS is a little high, mainly because of the shallowness of the loch. Even slight trade winds will turn the clear water into a murky water. As compared with Table 7, the obtained study results show much improvement in the estuarine water quality.

A comparison of West Loch water quality parameters in 1973 and this study's water quality laboratory results are tabulated as shown in Table 9. Most of the water quality parameters analyzed show much improvement except for total phosphorus, and total Kjeldahl nitrogen. These increased water quality parameters maybe due to the increase in surface runoff from adjacent agricultural fields, golf courses, and residential development.

Chapter 5

Conclusions and Recommendations

This study shows an improvement in the water quality at Waikele Stream and at West Loch Estuary. The improved water quality was a positive effect of the cessation of effluent discharge from the Mililani WWTP into Waikele Stream since 1986. Although significant progress has been made in improving the nation's water quality over the past twenty years, many coastal areas continue to suffer from persistent environmental problems and can expect to encounter new problems in the future.

This study was short in duration, and hence, may not convey a meaningful baseline analysis. It is recommended that when resources and funding become available, the monitoring program be continued at a longer duration in order to have a year round representation.

As evidenced by comparing the water quality data a little over ten years ago with the current study results, both the Waikele Stream and the West Loch Estuary water quality show significant improvement. It is apparent that reduction in point source discharges alone will not bring about the needed improvements in water quality that are targeted by the Federal and State regulations. Significant amounts of pollution arise from non-point sources.

The Pearl Harbor drainage basin encumbers vast agricultural land, and residential development that causes surface water runoff pollution. The pressure to free up land for housing outweighed desires to preserve agricultural land. Central Oahu and the Ewa Plain are undergoing rapid urban growth. Occurring simultaneously with this growth is the increase of surface runoff. The ongoing construction of the H-3 tunnel has had a tremendous impact on the thick sediments on Pearl Harbor basin (Water Engineering Technology, 1991), which is echoed by this study, and also reported in the 1969 FWPCA report on Waikele Stream carrying 4,250 tons per year of sediments onto West Loch, and eventually at Pearl Harbor. These sediments that settles in the Pearl Harbor channel make it a requirement for the Navy to perform periodic dredging in order to maintain the necessary navigable depth. With the other ongoing studies on both the East and West Mamala Bay, and with the Pearl Harbor Naval Complex as a whole being included in the National Priority List (NPL) should allow for more opportunity to clean, improve, and maintain a swimmable and fishable Pearl Harbor.

Navy Public Works Center - Environmental Laboratory, Code 330
Pearl Harbor, HI 96860-5470
Phone (808) 474-3704, FAX (808) 471-4534

Job Order, ESA Number 156-5071
Contact Person LT MANGLALLAN
Phone Number (HOME) 687-3602

Report to LT MANGLALLAN
Address COMNAVTACENGCOM PACDIV (N113)
(W) 474-7624
(H) 687-3602

MATRIX (Please check only one)

[ ]	Oil	[ ]	Soil
[ ]	Paint Chips	[ ]	Wastewater
[ ]	Potable Water	[ ]	Wipes
[ ]	Sludge	[X]	Other (Specify) STREAM WATER

Lab Number	Sample Identification/Description	Sampling Date	Sampling Time	Residual Chlorine (ppm)	Number/Type of Containers	Field/Lab Preservation	Analysis Required	Storage Area	Analysis Code
94-05075	1	24 MAR 94	1045		(2) 1-L PLAS	N/A	PH, COND, Cl^-, ALK, COD,		
					500 ml PLAS		TSS, NH_3, NO_2^-, NO_3,		
94-05076	2		1100		250 ml PLAS		TOTAL ORGN, TP, FC,		
					500 ml GLASS		Na, K, Ca, Mg, Cu, Zn,		
94-05077	3		1000		(4) VOA (40 ml)		Mn, Pb, Hg, BOD5,		
							FECAL COLIFORM, TURBIDITY,		
94-05078	4		0925				HEPTACHLOR, LINDANE,		
							ENDRIN, METHOXYCHLOR		
94-05079	5		1010				TOXAPHENE.		
94-05080	6		1030						

REMARKS (Special handling, field conditions, etc.)

Sampler(s)		Transported and Stored in	
Relinquished by	Date/Time 24 MAR 94 / 1127	Received by	Date/Time 5/24/94 1127

PH PWC 6280/4 (6-93)

White (Laboratory File Copy) Yellow (Client Copy) Pink (Branch Copy)

Appendix A PWC Environmental Lab Chain of Custody Form

Navy Public Works Center - Environmental/Industrial Laboratory, Code 330
Microbiological Laboratory Sampling, Processing and Analyses Record
Membrane Filtration Method for the Detection of Fecal Coliform Bacteria

JOB ORDER NUMBER	LAB NO.	SITE DESCRIPTION	RESIDUAL CHLORINE	SAMPLING TIME	MEMBRANE FILTER (VOLUME FILTERED COUNT)			FECAL COLIFORM BACTERIA (NO/100 mL)
156-5071		1		1045				
		2		1100				
		3		1000				
		4		0925				
		5		1010				
		6		1030				

Collected by [illegible] on 24 MAY 94
Relinquished by [illegible] on 24 MAY 94 at 1127
Received by [illegible] on [illegible] at [illegible]
Relinquished by _____ on _____ at _____
Received by _____ on _____ at _____
Temp Control Initial [illegible] Final [illegible]

Processed by _____ on _____ at _____
Read by _____ on _____ at _____
Controls _____ 3 _____ 4 _____ 5 _____
E. coli _____ Enterogenes _____
Reported by _____ on _____ at _____

Appendix A - PWC Environmental Lab Chain of Custody Form (continued)

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